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Microbiological Alterations in Distributed Water Treated with Granular Activated Carbon

Rensselaer Polytechnic Inst., Troy, NY

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16. ABSTRACT

The goal of this project was to examine the effect of granular activated carbon (GAC) treatment on the microbiological characteristics of potable water in distribution systems. Data was collected from both field and pilot plant studies.

Field monitoring studies from two water treatment plants indicate that treatment with GAC effects an increase in standard plant count (SPC) organisms. No other effect was observed. Post-chlorination negated the impact of the increase in SPC organisms.

Pilot plant studies indicated that longer bed contact time, as achieved by increasing the height of the bed, tended to increase microbial growth. Lowered velocities tended to decrease microbial growth. Increased levels of prechlorination yielded higher microbial counts on the carbon surface and slightly increased the number of bacteria in the effluent.

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MICROBIOLOGICAL ALTERATIONS IN DISTRIBUTED WATER TREATED WITH GRANULAR ACTIVATED CARBON

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This report examines the impact of granular activated carbon treatment on the microbiological water quality of potable water in a full scale installation, and the effect of operating variables on microbial quality in pilot plant units. Implications of this study for the use of activated carbon in widespread applications are discussed.

Francis T. Mayo
Director
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ABSTRACT

This research program was examing the possible effect of granular activated carbon treatment, on microbiological characteristics of potable water in distribution systems. To accomplish this objective, a field monitoring program on two water treatment plants and a series of pilot plant studies were conducted.

Field studies were conducted at Manchester, NH,a full scale water treatment plant employing granular carbon contractors, and at Concord, NH, a similar water treatment plant without carbon treatment. Parameters measured bi-weekly, Included coliforms, acid-fast bacteria, standard plate count, endotoxins, membrane standard plate count, chlorine residual,temperature, total organic carbon, pH and turbidity. Sampling from raw, partially treated, and finished waters at various locations within the distribution system was performed over an 18 month period. This study indicates that granular activated carbon treatment does effect an increase in standard plate count and membrane standard plate count organisms, but in no other microbial variate. Furthermore, conventional post-chlorination, as practiced at Manchester, appeared to mitigate any impact on the distributed water quality. Within the water distribution system, pH, temperature, and turbidity tended to be positively correlated with standard plate count membrane standard plate count densities, whereas chlorine concentrations were sporadically inversely related to microbial concentrations.

Pilot plant studies were conducted using coagulated, filtered water from the Troy, NY treatment plant. Three sets of experiments were conducted. The first examined the effect of bed height, the second examined the effect of superficial velocity, and the third examined the effect of prechlorination on microbial changes through the contractor. A longer empty bed contact time achieved through greater bed depth tended to increase microbial growth; however lowered velocity tended to decrease microbial growth. Higher levels of prechlorination yielded higher bacterial counts on the carbon surface, and slightly increased the microbial concentration in the effluent.

This report was submitted in fulfillment of Cooperative Agreement R-80-7172-010 by Rensselaer Polytechnic Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period January 1, 1980, through March 31, 1982, and work was completed as of March 31, 1982

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LIST OF ABBREVIATIONS FOR STATISTICAL ANALYSIS

SPC -- standard plate count
m-SPC -- membrane - standard plate count
TCOLI -- total coliform
AF -- acid-fast
ENDOT -- total endotoxins
ENDOF -- free endotoxins
CLF -- free chlorine
CLT -- total chlorine
TEMP -- temperature
TURB -- turbidity
TOC -- total organic carbon
DO -- dissolved oxygen
SDATE -- sin transform date
CDATE -- cosin transformed date

Abbreviations for the three pilot unit studies are found in Table 6.

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CONVERSION FACTORS FOR NON-METRIC UNITS

1 million gallons/day (MGD) = 0.04381 m^3/s

1 gallon/day-ft^2 = 0.04074 m/d

1 foot = 0.3048 m

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SECTION 1
INTRODUCTION

OBJECTIVES OF THE STUDY

The objectives of this research was to assess of microbial alterations in the potable water during granular activated carbon (GAC) treatment and in water distribution systems following conventional and conventional plus GAC treatment.

Specifically, the following questions were addressed:

1. What are the effects of GAC Treatment microbial quality of a finished water, and water at its point of use?
2. What are the effects of disinfectant residual and substrate concentration on microbial survial in the potable water milieu?
3. What are the effects of variations in GAC loading conditions on microbial dynamics within the carbon bed?

SUMMARY OF PREVIOUS WORK

Recent concerns for minimizing of byproducts from the chlorination of potable waters have led to proposals for introducing GAC treatment into the treatment sequence and reducing dose to the lowest amount needed to prevent significant survival of accidentally introduced microbial populations. For a rational understanding of constraints involved in such decisions, it is necessary to understand the dynamics of microbial population in GAC and in water distribution systems.

The growth of microbial slimes in water distribution systems is a complex phenomenon. Lee *et al.* (1977) have noted that the extent of regrowth in a simulated distribution system was a function both of the applied disinfectant (chlorine) dose and the organic carbon concentration. In addition to organic carbon, which may serve as a growth substrate for microbial growth, recent workers (Burman and Colbourne, 1977; Schoenen and Dott, 1977) have indicated that plumbing materials used in water supply construction may serve as media for the propagation of microorganisms.

The process of microbial growth in distribution systems is not well characterized, either biologically or kinetically. Both Allen *et al.* (1977)

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and Lee *et al.* (1977) have noted the importance of chlorine residual as a determinant of microbial growth in water distribution systems. Bryers *et al.* (1978) and Bryers and Characklis (1977) have investigated the effects of chlorination on microbial slimes attached to surfaces. They concluded that, while reasonably accurate semi-empirical models could be constructed which described hydraulic properties of attached slimes, it was more difficult to describe the production of suspended solids resulting from the chlorination of such slimes. It would be anticipated that viable microorganisms would be contained in such suspended solids.

If microbial increases were due primarily to growth of organisms in the liquid phase, a simple model could be proposed to relate organism density, disinfectant concentration, substrate concentration, and elapsed time in the distribution system. The following are assumed:

1. The distribution system can be described as a plug flow reactor, with constant inputs.
2. Microbial inactivation by disinfectant occurs at a rate which is first order both in surviving microorganisms and disinfectant concentration--i.e., Chick's Law applies.
3. Microbial decay due to other forces may be predicted by an endogenous decay constant. These forces may include physical factors, such as sedimentation or mass transfer to the pipe walls, or biological factors which remain constant with time.
4. Microbial multiplication may be described according to Monod kinetics, assuming substrate depletion is negligible. The latter is valid at microbial densities up to and including levels at which hygienic concern arises.
5. Disinfectant decomposition is first order.

Under these conditions, a mass balance on microorganisms in the distribution system can be written as (Haas, 1981):

$$\frac{dN}{dt} = \left(\frac{\mu_M S}{S + K_s} - k_d - k_1 C_o e^{-k_2 t}\right) N \qquad (1)$$

where N is viable microorganism concentration, S is substrate concentration, C_o is disinfectant concentration *ab initio*, t is residence time in the distribution system, k_1 is the rate constant for disinfectant-dependent inactivation, k_2 is the rate constant for disinfectant decomposition, and the other parameters are classical kinetic constants (e.g., Metcalf and Eddy, 1979). Equation 1 may be integrated to yield:

$$\ln(N/N_o) = \left(\frac{\mu_M S}{S + K_s} - k_d\right) t - \frac{C_o k_1}{k_2}\left(1 - e^{-k_2 t}\right) \qquad (2)$$

If no reinoculation occurs in the distribution system (i.e., no cross-contamination, and no input from the slime phase), then a necessary and sufficient condition for lack of microbial regrowth is that the right-hand side of equation (2) will always be less than zero.

If reinoculation occurs, then a conservative criteria might be that a net inhibitory potential always exists in the distribution system. This may be expressed mathematically by requiring that dN/dt always be negative. In this case, equation (1) can be rearranged to yield a criteria for lack of regrowth. It can be shown that this test, equation (3), is always more rigorous than that imposed by equation (2).

$$C_o > \frac{1}{k_1} \left(\frac{\mu_M S}{S + K_s} - k_d\right) e^{k_2 t} \qquad (3)$$

Equation (3) readily shows that the initial dose of disinfectant required to prevent regrowth is a function of the residence time in the distribution system and the initial substrate concentration present. Unfortunately, no experimental test of this type of model is known.

The persistence and growth of microorganisms upon GAC filter beds has only recently been of concern in the water supply field. Activated carbon can act to remove viruses from water, by a combination of filtration and adsorption (Cookson et al., 1967; Cookson, 1967, 1970). Early studies in the microbiology literature indicated the ability of charcoals to remove various groups of bacteria from solution at pH-dependent and species-dependent levels. The kinetics of bacterial adsorption were found to be rapid (Gunnison and Marshall, 1937). Viral adsorption from solution has been treated quantitatively from diffusional theory (Valentine and Allison, 1959), from a mass-transfer point of view (Cookson, 1970), and utilizing the approach of second-order kinetics (Cookson et al., 1967).

Daniels (1972) has reviewed the literature on interactions of microorganisms with solid surfaces, and concluded that the process may be treated according to classical theories of adsorption. A major factor not covered in his review, nor in the reports of most workers, was the possibility of microbial increase while adsorbed to a carbon surface.

That the GAC surface possesses considerable biotic activity has been convincingly demonstrated by Weber et al. (1978). Given the hydrophobic nature of the exterior of many microorganisms, it is to be expected that these organisms would concentrate at interfaces. Interfacial concentration of microorganisms at the surface microlayer of natural waters has been reported by two groups in recent years (Hatcher and Parker, 1974; Dutka and Kwan, 1978). It is therefore not unreasonable to anticipate that microorganisms may accumulate at the solution-activated carbon interface.

Inasmuch as the concentration of organic material at the GAC surface is also higher than the bulk solution concentration, the organisms which are transported to the carbon surface are exposed to increased nutrient concentrations. In the presence of these enriched nutrient levels, it would be anticipated that both growth rate and microbial yield would be enhanced.

This effect of interfacial area upon microbial dynamics has been known since the work of Zobell and Anderson (1936), where it was observed that marine bacteria incubated in identical containers, but in smaller volumes of fluid grew to larger densities than organisms grown in larger volumes.

The study of Stamm et al. (1969) indicated that growth of bacterial species was possible in ion exchange resins used for on-site water softening. Several species were observed to increase in numbers within the resin bed, including Flavobacterium, Mycobacterium, and Pseudomonas. It was suggested that the increased interfacial concentration of organic material on the resin promoted microbial growth. Concentrations of microorganisms to 10^7/ml were recorded.

Four recent studies have evaluated microbial water quality alterations resulting from use of home water purifiers containing granular or powdered activated carbon. While operational conditions of these devices are rather different than GAC beds operated in a full-scale water treatment facility, they may provide worst case estimates for microbial quality alterations.

Wallis et al. (1974) filtered Houston tap water thru various home water purifiers, and observed increases in bacterial concentration in the filter effluents after increasing eluted volumes. Aerobic plate counts were increased by passage thru the column, from a value of .01 - 1 CFU/ml in the influent to 3-1 x 10^4/ml in the effluent. The authors suggested that inadvertant low-level concentrations of pathogens in the tap water could be concentrated and multiply in the carbon bed to levels of health significance, or that the large population of organisms present in the bed could release toxins of health concern.

Hanes et al. (1978) monitored bacterial concentration before and after passage thru several proprietary home water purifiers containing activated carbon. All purifiers, during conditions of high volumetric flow rate, caused an increase in standard plate count across the device. In a similar study, Burkhead et al. (1978) observed that passage of tap water thru various home water purifiers resulted in an increase in the proportion of samples which contained greater than 500 CFU/ml, as determined by the standard plate count. While the authors also commented upon relationships between effluent chlorine residual, influent chlorine residual, and plate count, and attempted a qualitative correlation, it is not readily apparent that the data are significantly correlated in this manner. Nevertheless, their results on regrowth are in accord with the prior studies on this matter. In addition, Burkhead et al. (1978) were able to confirm the most frequent isolate from their water samples as being a member of the genus Pseudomonas.

The studies of bacterial regrowth on home carbon filters were cast into controversy by the work of Fiore and Rabineau (1977), who found that, while passage of tap water thru a carbon home water filter increased standard plate count, holding water for equivalent time periods in the absence of carbon contact also resulted in elevated bacterial levels. Coliforms could be detected in the influent and effluent to carbon columns at similar levels, suggesting that regrowth of coliform organisms may not be of significance.

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In one of the first studies of GAC as used in potable water treatment Wolf et al. (1978) monitored bacterial quality of carbon treated waters, and conducted test to determine levels of bacterial endotoxins present and pyrogenic activity. Grab samples were obtained and standard plate count and bacterial endotoxin levels were measured. In 7 of 28 samples reported, an increase in standard plate count occurred through the GAC bed. In 4 of these 7 cases, free chlorine was reported to have been present at the bed inlet, at levels up to 1.5 mg/l. No increases in total coliforms across the bed were reported, although nearly all values obtained were below detectable limits, so quantitative conclusions are difficult to draw. An increase in endotoxin levels was reported in two cases, both of which increases in standard plate count occurred. One of the authors' recommendation was "...since prechlorination practice might in the future be minimized to control trihalomethane content, it is strongly recommended that studies of GAC and its impact on the microbiological quality of processed waters be implemented on a variety of waters wher the prechlorination process is not employed."

More recent investigations at several full scale GAC installations suggest that coliforms present in the process influent may colonize carbon columns, at least temporarily, particularly at higher temperatures. However adaquate final disinfection suffices to maintain the finished water coliform and Standard Plate Count concentrations at acceptable levels (Symons et al 19-1).

In addition to evidence in the work noted above, there is cause for concern regarding the presence of other groups of organisms in potable water supplies, In particular, a significant group of organisms may be the acid-fast bacteria, members of the genus Mycobaterium . Recent evidence suggest that these organisms are present in water, are resistant to many common disinfectants, possess surface active properties which would promote retention, survival and regrowth in distribution systems and GAC beds, and are not enumerated readily on conventional media.

There is considerable evidence to suggest that acid-fast organisms are very prevalent in water and wastewater. Edwards and Palmer (1959) hypothesized that a typical mycobateria might be transmitted by food or water., Kubica et al. (1961) expanded this hypothesis by speculating that atypical mycobacteria exist in soil, which serves as a reservoir, and are transmitted by the water route to man or animals by inhalation or ingestion. This hypothesis has been restated by Gale (1976).

Atypical mycobacteria can be isolated from human fecal material from healthy subjects (Rosebury, 1962; Engelbrecht et al ., 1974) Engelbrecht et al.(1974) found Group IV atypical acid-fast bacteria in over 40 percent of the stool samples examined from apparently healthy subjects; the mean density was 18.9 acid-fast organisms/g.

These orgainisms may also be excreted by some animals; Jones et al. (1976) were able to isolate rapid growing mycobacteria from piggery waste.

Isolation of various species of Mycobacterium from tap water points to their resistance to conventional water treatment unit operations. McSwiggan and Collins (1974) isolated M. xenopi and M. kansasii from drinking water. Various mycobacteria were isolated from raw and treated drinking waters by Goslee and Wolinsky (1976). Gangadharam et al. (1976) observed frequent isolates of M. gordonae in tap water.

The resistance of M. marinum to 30 minute exposure of 1.5 mg/l free available chlorine in swimming pool disinfection has been noted (Park and Brewer, 1976). The resistance of M. fortuitum to many disinfectants is recognized by procedures established under the British Diseases of Animals Order, which prescribe this organism as a test for disinfectant potency against the tubercule bacillus (Trueman, 1971).

The work of Engelbrecht et al. (1975) indicates that the rapid-growing atypical mycobacteria may be more resistant to chlorine, chloramines, and ozone, than other organisms. Distribution system studies indicate that these organisms can be detected in 7 - 36% of samples at an average density of 1.4 - 3.0 organisms/l (Engelbrecht et al., 1978).

Surface active properties of mycobacteria result from the presence of a very hydrophobic cell wall, rich in lipid material. This cell wall, which appears to be a primary factor conferring disinfectant resistance (Haas, 1978) would be expected to possess surface active properties. Experience of the principal investigator with pure cultures of these organisms suggests that they readily and preferentially accumulate at interfaces -- an indication of this surface active behavior.

It would not be expected that the acid-fast organisms could be enumerated on media used for general water bacteriology, such as Standard Plate Count Media, under standard conditions (Standard Methods, 1981). Incubation time for the enumeration of acid-fast organisms on optimal media is 72 hours at 37°C (Engelbrecht and Haas, 1977). Inasmuch as the standard plate count procedure requires only an incubation of 48 hours (Standard Methods, 1981), it would be expected that a substantial portion of the rapidly-growing acid-fast population would not be enumerated using the latter technique.

SECTION 2
CONCLUSIONS

1) Raw water qualities at Manchester and Concord are not different from one another for SPC, m-SPC, acid-fast, total coliforms and turbidity; however differences between the two plants were recorded for total endotoxin, pH, temperature, and TOC.

2) Microbial and physico-chemical papameters recorded at Manchester for finished and distribution samples are significantly different from comparable locations at Concord.

3) Other than a relationship between SPC and m-SPC organisms no consistent correlations among indicator organisms could be detected.

4) Total Organic Carbon was not found to be important in governing microbial concentrations in the water treatment and distribution systems examined.

5) Increasing values of pH, temperature, and turbidity are correlated with increasing concentrations of both SPC and m-SPC organisms.

6) Growth across the GAC filters for m-SPC was positively correlated to free chlorine and negatively correlated for total chlorine. There does not appear to be a relationship between the change in SPC through the GAC filters and either pH, temperature, free chlorine, total chlorine, turbidity or TOC.

7) While both prechlorination and postchlorination have been found to lower microbial concentrations, examination of the data collected in this study does not consistently support the hypothesis that chlorine residuals are inversely related to microbial concentration in distribution systems. In fact several significant correlations indicate that increasing levels of chlorine in distribution systems may lead to increasing microbial concentrations.

8) Full scale GAC treatment as practiced by Manchester, NH resulted in a statistically significant increase in SPC and m-SPC organisms averaging 0.649 and 0.743 logs, respectively. For acid-fast, total coliforms and total endotoxins no statistically significant effect was noted. However, conventional postchlorination as practiced at Manchester appears to mitigate the impact of these effects in the distribution systems.

9) Though the correlations between endotoxins and various indicator organisms are statistically different from zero, their absolute values are relatively low. Thus from a practical point of view, the utility of the LAL endotoxin assay as a surrogate for indicator organisms is minimal.

10) For virtually all subsets of the data examined, there was a high statistically significant correlation between SPC values. In may cases, however, there is a numerical difference between the values of these parameters recorded at a given station or time. This suggest that though the m-SPC procedure is a useful substitute for the SPC procedure the numerical relationship between these two parameters is not a universal one. Nevertheless, the m-SPC procedure is a useful one in a given location, provided that a site specific standard curve is established, in much the same way that TOC is used as in indicator for BOD in wastewater treatment.

11) Low temperatures, high dissolved oxgen and turbidity in both the influent and in the effluent of the GAC pilot unit were associated with higher regrowth of microorganisms on GAC. This was also seen in the values for the number of bacteria per gram of wet carbon.

12) Free and total endotoxins do not produce a good estimate of indicator organisms in the GAC Pilot unit effluent.

13) GAC column effluent compared with the influent exhibited a significant decrease in free and total chlorine and a significant increase in m-SPC values.

14) m-SPC was not a good indicator of SPC for any of the pilot unit experiments.

15) Increasing the empty bed contact time through the pilot unit's GAC columns produced a corresponding increase in SPC and m-SPC levels.

16) Increasing the dose of free chlorine into the pilot unit's GAC columns resulted in greater numbers of bacteria per gram of wet carbon.

SECTION 3
MATERIALS AND METHODS

INTRODUCTION

The physical, chemical and biological techniques used for both the field and pilot studies are contained in this section. The rationale for the selection of the field sampling sites as well as the construction of the pilot unit GAC column are also discussed.

FIELD SAMPLING SITE SELECTION

Field Study

Several possible water treatment systems were investigated as field sampling sites. It was ascertained that the Manchester, New Hampshire system using GAC was the most suitable choice of a plant utilizing activated carbon as it is employed for organic removal. This plant uses Massabestic Lake as a source water and utilizes alum/aluminate coagulation, prechlorination, sand filtration, GAC treatment, and post chlorination sufficient to produce approximately 1 mg/l free residual chlorine leaving the plant (Table 1). The GAC bed was thermally reactivated every 90 to 120 days till May 1981 when reactivation was discontinued. Finished water is distributed to two reservoirs (one covered) which serve two distinct systems within the city. The distribution system selected for study was a gravity fed system serviced from the covered reservoir, that extends to approximately five days residence time. The residence time in the reservoir was approximately three days. Eight sampling points were chosen as listed in Table 2. A flow diagram indicating each sampling point is shown in Figure 1.

To qualitatively assess the effect of GAC treatment on distribution system microbial dynamics, it was decided to search for a control plant. Desired features of such a system included similarity of source water and treatment sequence (excepting GAC), existence of a long distribution system branch, and proximity to both the university and the Manchester, NH location.

As a control plant to Manchester, several possible systems were investigated. On the basis of the above criteria and willingness of plant personnel to cooperate in the study, the Concord, New Hampshire system was selected. This facility employs Penacook Lake as a source water and utilizes permanganate treatment, plain sedimentation, filtration and post-chlorination to approximately 0.25 mg/l free chlorine (Table 3). The plant incorporates a 12

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TABLE 1. OPERATIONAL PARAMETERS OF MANCHESTER, NH WATER TREATMENT PLANT

Parameter	Description *
Design Capacity:	40 mgd
Presently Treating:	13 mgd (yearly average)
% to Study System:	40%
Raw Water:	Massabesic Lake, Protected, Class A
pH:	6.0 - 6.5
Alakinity:	3.4 mg/l $CaCO_3$
Hardness:	12.0 mg/l $CaCO_3$
Turbidity	0.5 NTU
Color	15.0 APHA
Prechlorination:	Sodium Hypochlorite
Demand:	1.0 - 1.5 mg/l
Cl_F	0.5 mg/l (summer), 0.1 - 0.3 mg/l (winter)
Coagulation:	alum/aluminate
Dose:	9.0 mg/l
Sedimentation:	
Sand filters:	sand/anthracite
Depth:	11.0 in. (sand)
Velocity:	1.5 gpm/ft^2
Backwash:	once/day filter time
GAC Filter:	Westvaco WVW 8-30
Depth:	48 in.
Velocity	1.5 gpm/$ft.^2$
EBCT:	8 min. (maximum flow)
Reactivation	90 - 120 days (terminated May 1981)
Backwash	1/day
Post Chlorination:	Sodium Hypochlorite
Demand (Cl_F)	0.1 mg/l
Cl_F	1.5 mg/l

* Conversion factors for non-metric units are given on Page xv

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TABLE 2. MANCHESTER, NH SAMPLING SITES

Designation	Location
M1	Downstream of mixing chamber between raw water and recycle from sludge/backwash settling lagoon
M2	Downstream of coagulation/sedimentation and prechlorination
M3	Downstream from filtration
M4	GAC effluent
M5	Finished water at plant tap
M6	Station 7L -- Manchester Water Works Main Street Office
M7	Station 12L -- S. Main Street Fire Station
M8	Station 15L -- Wayfarer Motor Inn (approx. 1 wk. in system)

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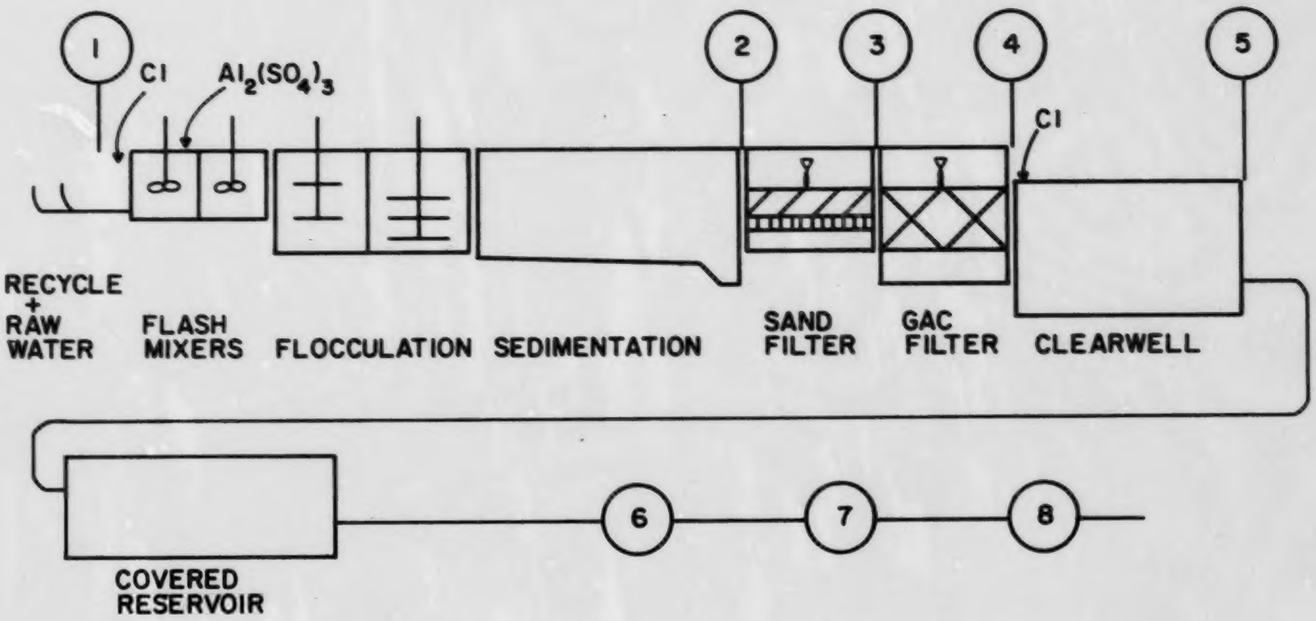

Figure 1. Flow Diagram for Manchester, NH

TABLE 3 OPERATIONAL PARAMETERS OF CONCORD, NH WATER TREATMENT PLANT

Parameter	Description
Design Capacity:	10 mgd
Presently Treating:	6 - 8 mgd (yearly average)
% to Study System:	10% @ 8 mgd
Raw Water:	Penacook Lake, Protected, class A
pH:	6.8 - 7.0
Alkalinity:	11.0 mg/l $CaCO_3$
Hardness:	28 - 30 mg/l $CaCO_3$
Turbidity:	0.25 NTU
Color:	5.0
Prechlorination:	none
Preliminary treatment:	Potassium permaganate and caustic addition
pH:	9.4 - 10.0
Coagulation:	not in use
Sedimentation:	flow through tank
Sand Filters:	sand/anthracite
Depth:	15.0 in, (sand), 24 in (anthracite)
Velocity:	4.5 gpm/ft^2
Backwash	twice/month
Post Chlorination:	Sodium hypochlorite
Demand (Cl_F)	0.9 mg/l
Cl_F	0.2 - 0.3 mg/l

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hour finished water reservoir within the plant and the treatment processes are shut down from 10:30 p.m. till 7:00 a.m. daily. Five in-plant stations and three stations within a three mile section of the distribution system were selected for sampling (Figutr 2). The sampling locations are listed in (Table 4).

Pilot Unit Study

Two constraints that needed to be met in choosing the site for the pilot unit study site were nearness to the university, since daily monitoring of the system was needed, and high degree of cooperation from plant personnel in keeping the researchers informed about any alterations in plant operations and performance and to observe the columns for malfunctions. It was impossible for the researchers to be constantly at the plant to monitor the columns.

On that basis the Troy, New York, Water Treatment Plant was chosen for the Pilot Study. The Troy plant is a 30 mgd facility, employing alum coagulation, filtration and pre- and post chlorination, using the Tomhannock Reservoir as a source water (Table 5).

CONSTRUCITON OF THE GAC PILOT UNIT

Design Constraints

The pilot unit was constructed so that Empty Bed Contact Time (EBCT) could be varied either by changing the depth of the carbon bed or the flow through the column. In this way the effects of several operational variables could be studied without any major changes in the apparatus. In addition to the effect of EBCT and superificial velocity (flow), pre-chlorination of the influent to the columns was also studied (Table 6). Four parallel and identical columns were constructed to permit three simulataneous values of the design variable under investigation and a control (empty column).

The initial study was conducted by bed depth, keeping the velocity through each column the same. In accordance with possible practice an EBCT of two, five and ten minutes with an empty column residence time of ten minutes, and a face velocity of 3 gpm/sq.ft.was used. This maximum column size would be needed for this initial study and the design of the columns was based on a maximum EBCT of ten minutes with a face velocity of 3 gpm/sq. ft. (flow = 60 ml/min) with enough room for 50% expension during backwashing.

Column Construction

One inch inside diameter Cadco LEan Polycarbonate tubing (Cadillac Plastic Co., Albany NY) was chosen for construction of the columns. Based upon the constraints previously discussed a column height of six feet was needed. An additional one foot was added in order to accommodate six inches of small rocks on the bottom of the column (to distribute backwash water)

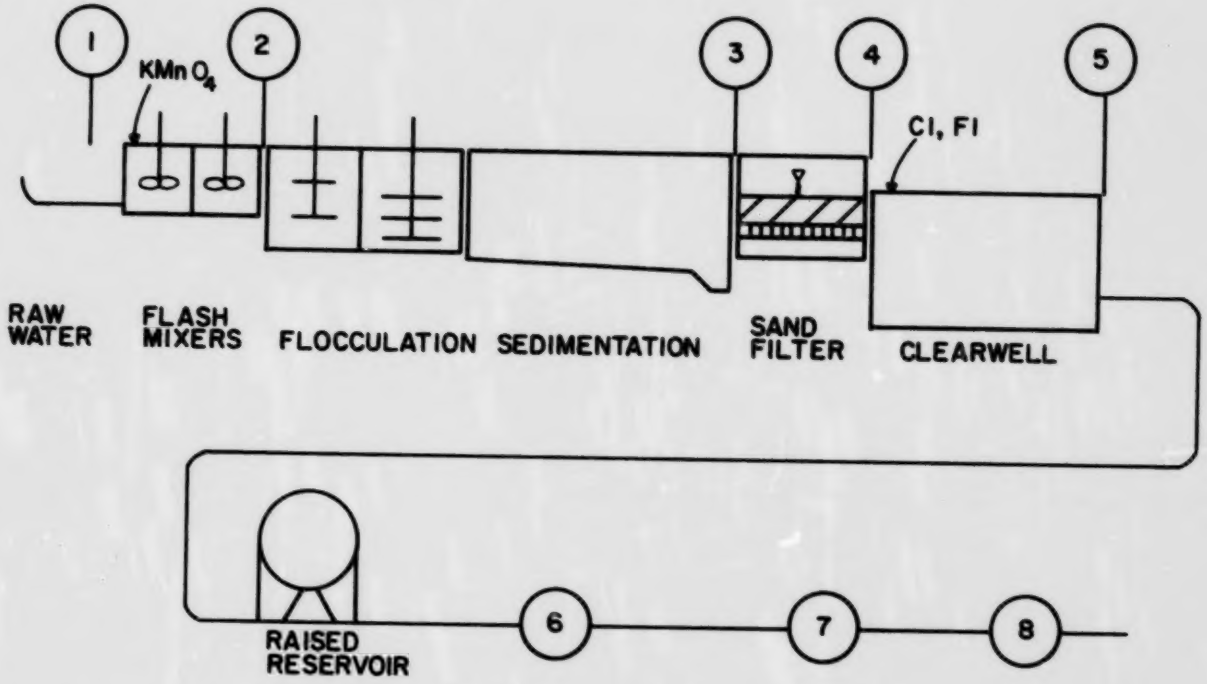

Figure 2. Flow Diagram for Concord, NH

TABLE 4. CONCORD, NH SAMPLING SITES

Designation	Location
C1	Raw water
C2	Immediately downstream of permanganate and caustic addition
C3	Following plain sedimentation
C4	Filter effluent
C5	Post-chlorinated, finished water at plant tap
C6*	Philips 66 Gas Station
C7	Penacook Fire Station
C8†	The Apple House (Fruit Distributor)

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*after 12/2/80 Cumberland Farms

†8/25/81 Bonny's Flower Shop

TABLE 5. OPERATIONAL PARAMETERS OF TROY, NY WATER TREATMENT PLANT

Parameter	Description
Design Capacity:	45 mgd (Present Capacity: 30mgd)
Presently Treating:	16 mgd (yearly average)
Raw Water:	Tomhannock Reservoir, Protected, Class A
pH:	7.34
Alkalinity:	25.6 mg/l as $CaCO_3$
Hardness:	55-75 mg/l as $CaCO_3$
Turtidity:	1.85 NTU
Color:	13 APHA units
Prechlorination:	
Cl_F:	1.1 - 1.5 mg/l (residual)
Coagulation:	alum
dose:	16.1 mg/l (average)
Sedimentation:	none
Sand Filters:	sand/anthracite
Depth:	18 in (sand) 18.in (anthracite)
Velocity:	3 gpm/ft^2
Backwash:	5 days
Post Chlorination:	
Demand (Cl_F)	0.21 mg/l
Cl_F:	0.60 (residual)

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TABLE 6. OPERATIONAL CONDITIONS FOR PILOT UNIT STUDY

Run	Column	EBCT Min	GAC Depth (ft)	Flow ml/min	Addition Dose Chlorine mg/l
RUN #1	T1 (control)	-	0	60	*
	T2	2.5	1	60	*
	T3	5	2	60	*
	T4	10	4	60	*
RUN #2	T1 (control)	-	0	60	*
	T2	3.75	2	120	*
	T3	5	2	60	*
	T4	10	2	45	*
RUN #3	T1 (control)	-	0	60	*
	T2	5	2	60	1.0
	T3	5	2	60	*
	T4	5	2	60	0.7

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*Cl residual from sedimentation basin (average 0.3 - 0.5 mg/l) evenly and to provide a base for the carbon (Symons, 1978) and to provide at least six inches of freeboard above that needed for backwashing (Figure 3). Three ports were installed in the side of the columns, one below the surface of the rock layer for a manometer and two spaced a foot apart above the rocks for sampling ports.

Column influent consisted of post-filtration water which was continually fed into a 10 gallon constant head reservoir then pumped to the column. A constant flow to each unit was maintained and was controlled by a valve in the effluent line. All excess water exited through an overflow approximately 10 cm from the top of the column. Backwashing was accomplished through the adjustment of the flow alteration clamps (FAC) with the backwash flow being controlled by the pump. A flow scheme for both the running of the column and backwashing is shown in Figure 3.

In contrast to the first column study, in which EBCT was controlled by bed depth, the second column study controlled EBCT by varying the flow while keeping bed depth constant. A bed depth of two feet with flows of 6.0 3.0 and 2.25 gpm/ft^2 as well as an empty control column receiving 3.0 gpm/ft^2 were employed in this second run.

For the third column study the ten gallon reservoir was divided into three watertight sections. The first section was kept dry and the latter two were used as the reservoir for the column influent and a chlorine mixing chamber (Figure 4). The reservoir was gravity fed from a constant flow reservoir that was connected to the post-filtration water source. This assured that a constant flow would be maintained through the chlorine mixing chamber keeping the chlorine pumped to the columns relatively constant.

The chlorine fed to the columns was prepared by saturating 20 liters of tap water with ultra high purity chlorine gas. The concentrated chlorine solution (1200 - 1800 mg/l) was gravity fed to the overflow from the column influent chamber. This overflow mixture passed the chlorine mixing chamber. The diluted chlorine solution was pumped to the columns where the flow was split, fed through a valve to regulate the flow and fed to the influent line to each column. This run consisted of a control column (containing no GAC), and three parallel columns containing two feet of carbon. All units received a flow of 3 gpm/ft^2, and the influent chlorine concentration to the three carbon columns was varied so that one unit received water containing 0.3 - 0.5 mg/l free residual resulting from prechlorination, and the remaining two units were dosed to 0.7 and 1.0 mg/l free chlorine above that level (Table 6).

PHYSICAL AND CHEMICAL METHODS

Temperature

A mercury-filled celsius thermometer with one degree graduations was used to record temperature.

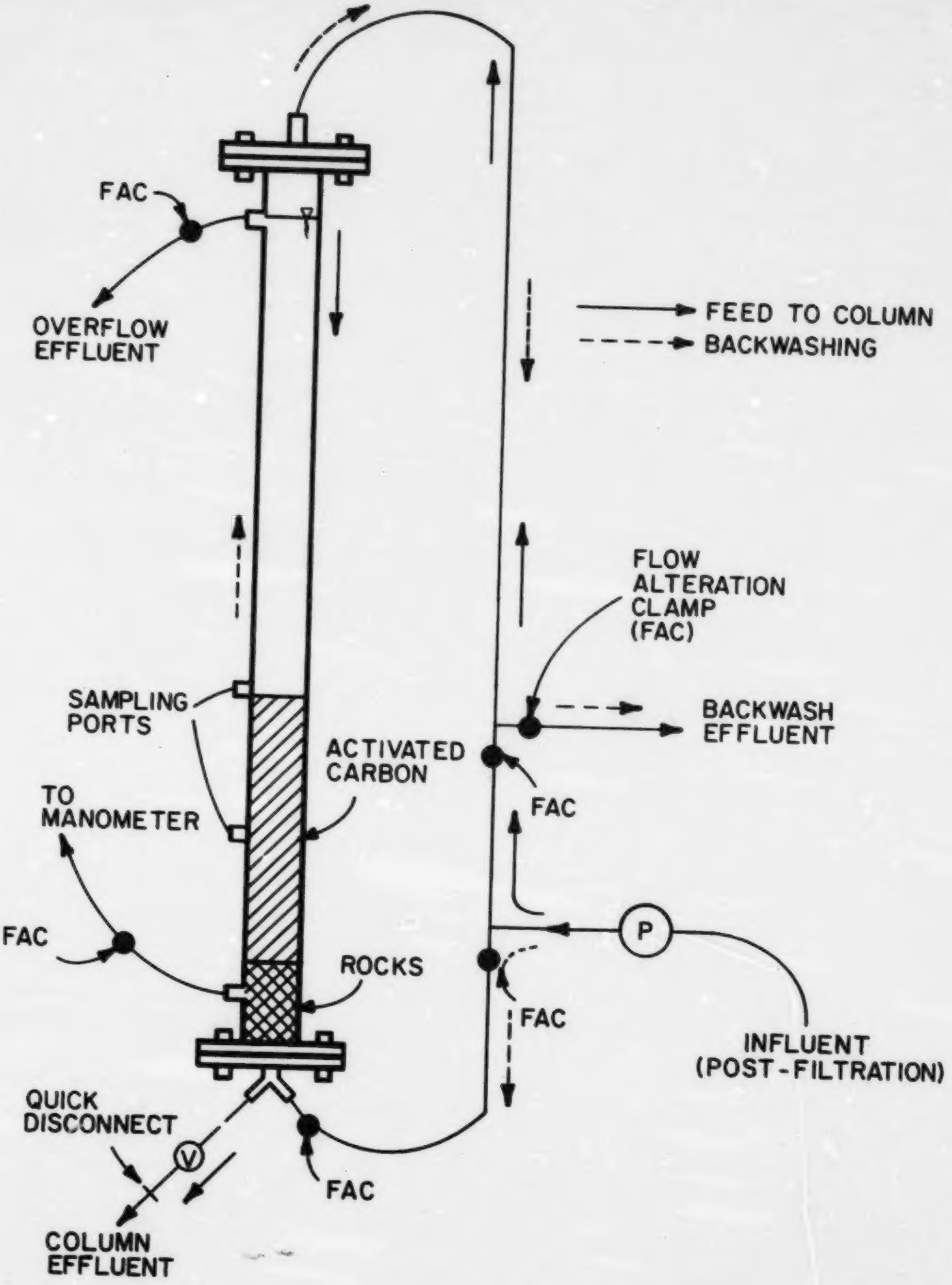

Figure 3. Flow Diagram for Pilot Unit.

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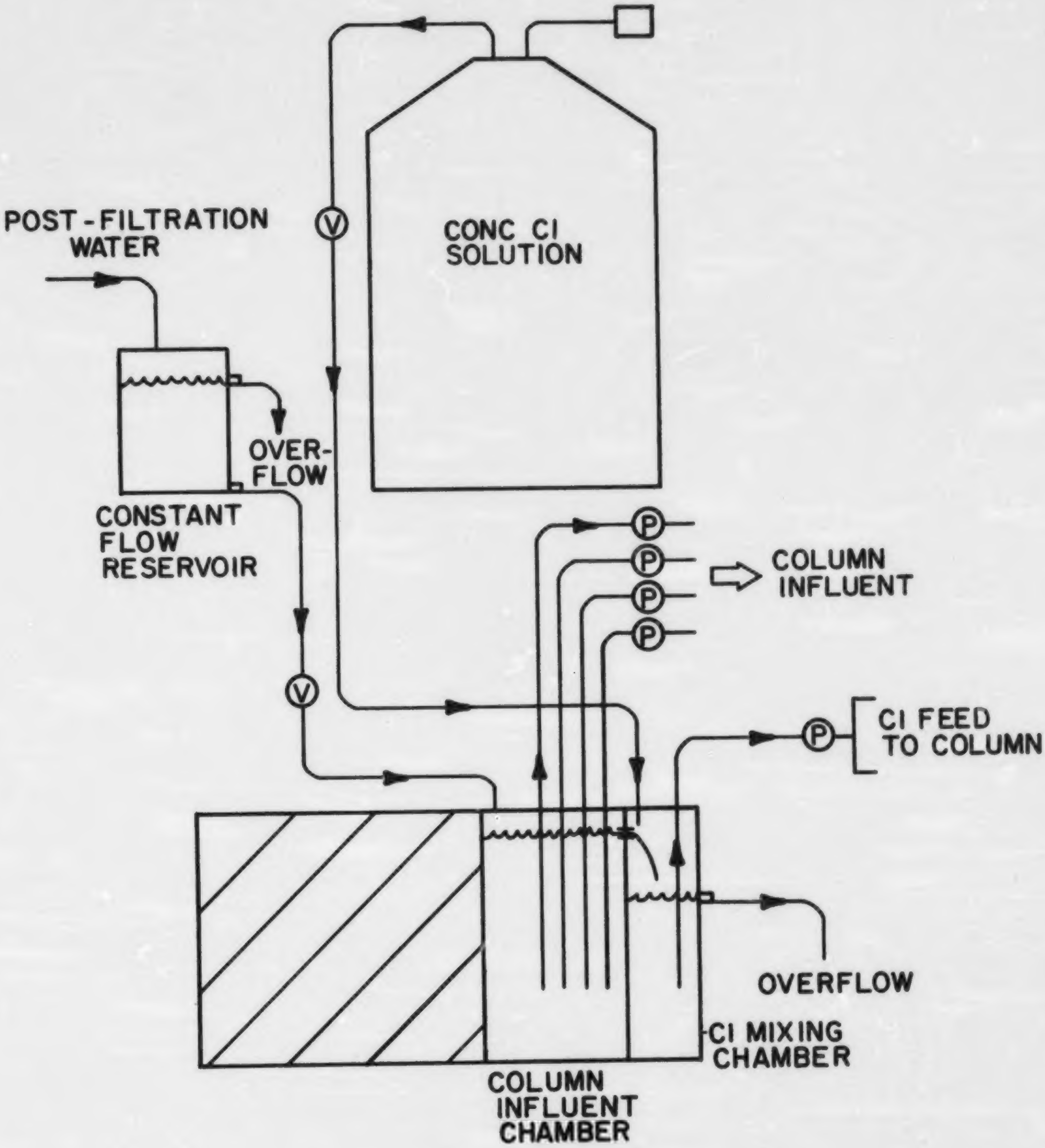

Figure 4. Chlorination System for Prechlorination Study.

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pH

pH was determined using the glass electrode method. (APHA et al, 1982)

Chlorine Residuals

Chlorine residuals were measured colorimetrically using a Hach Model CN-66 DPD Free and Total Chlorine Test Kit (Hach Chemical Co., Loveland, CO).

Dissolved Oxygen

Dissolved Oxygen (DO) measurements were obtained using a YSI Model 57 DO meter (Yellow Springs Instrument Co., Yellow Springs, OH).

Turbidity

Turbidity was measured using a Hach Model 2100 A Turbidimeter (Hach Chemical Co., Loveland, CO).

Total Organic Carbon

Total Organic Carbon (TOC) was measured using Beckman 915 A Total Organic Carbon Analyzer (Beckman Instruments, Palo Alto, CA) as given in Standard Methods (APHA et al., 1981).

Samples for laboratory analysis of turbidity and TOC were collected in sterile milk dilution bottles which were dechlorinated. Sterile, dechlorinated sample containers were used to insure suitable material if a microbiological sample was lost.

MICROBIOLOGICAL METHODS

Total Coliforms

Total coliforms were determined using the membrane filter procedure (APHA et al., 1981; Bordner and Winter, 1978). Sample volumes of one liter, where practicable, and 100 ml were filtered. After the first year of the study the 100 ml sample volume was eliminated from samples that routinely showed negative coliform growth. Verification of total coliform colonies consisted of the lauryl tryptose - brilliant green bile lactose broth method (APHA et al., 1981). A minimum of five sheen colonies per plate was confirmed, but when less than five colonies were available all sheen colonies were verified.

Standard Plate Count

Standard Plate Counts (SPC) were run on all samples in accordance with Standard Methods (APHA et al., 1981) with reference to Bordner and Winter, (1978). Sample volumes of 1.0 ml and 0.1 ml were used. On selected samples, parallel determinations using the membrane SPC (m-SPC) procedure of Taylor and Geldreich (1979) were performed. Ten ml and 1.0 ml sample volumes were used for the field study and the appropriate dilutions where required were filtered for the pilot unit study. Incubation was 48 hours at 35°C.

Acid-Fast

Enumeration of the acid fast bacteria was performed according to the membrane filter technique using the single step direct pretreatment filtration procedure as described by Englebrecht and Haas (1979). As with the coliforms, one liter, where practicable, and 100 ml samples were used. The 100 ml sample volume was eliminated from samples that routinely showed low (<10 colony forming units (CFU) or negative acid-fast growth. Occasional samples were incubated for up to 144 hours prior to enumeration. This did not seem to provide results differing from the routine 72 hours incubation.

Microbiological Sampling Container Preparation

Sterile eight liter Nalgene bottles (Nalge Co., Rochester, NY), with sodium thiosulfate as a dechlorinating agent (APHA et al., 1981) were used to collect samples for total coliforms, acid-fast, standard and membrane-standard plate counts. Since the pilot unit samples took between one and two hours to collect a sterile foil seal was placed over the mouth of the collection bottle to keep out foreign matter.

Endotoxins

Endotoxin levels were determined according to the procedure of Evans et al., (1978) using the Limulus Amebocyte Lysate (LAL) technique with spectrophotometric detection as developed by Associates of Cape Cod, Inc. (Woods Hole, MA). As in Evans et al. (1978) a modification was made in the Associates of Cape Cod protocol to reduce the amount of lysate used. Sample volumes were reduced from 1.0 ml to 0.5 ml and lysate from 0.2 ml to 0.1 ml. This procedure was discussed with Associates of Cape Cod before being implemented. The remainder of the procedure followed is the standard protocol provided by Associates of Cape Cod using 3% NaCl, an incubation time of one hour at 37°C, detection at 360 nm and construction of a standard curve for each vial of lysate used.

All glassware and reagents used in the analysis were pyrogen free. Glassware was heated for not less than three hours at 180°C. The reagent-grade NaCl was heated directly in the flask used to prepare the 3% salt solution and pyrogen free irrigation water (Travenol Laboratories, Inc., Deerfield, IL) was used in all preparations, with a new bottle being opened for each sampling trip. All pipettes used were sterile, disposable, borosilicate glass (Corning Glass Works, Corning, NY), which needed no additional treatment.

Caution was required with regard to reuse of glassware since even the smallest residue was found to give false positive results. It was found that keeping a set of glassware exclusively for endotoxins and using disposable incubation tubes gave best results.

Endotoxin samples were collected in 20 ml pyrogen-free borosilicate glass tubes which were treated with sodium thiosulfate before baking. Since the reaction of the lysate with the water sample is sensitive to the salt concentration (Evans, et al., 1978) this method was discussed with Associates of Cape Cod to assure that the sodium thiosulfate salt would not affect the analysis.

Free and total endotoxins were determined. After being received by the lab, the water sample was split into two aliquots. One was analyzed directly for total endotoxin while the second was centrifuged in pyrogen free centrifuge tubes using a high speed centrifuged at 1800 RPM for twenty minutes after which the supernatant was analyzed for free endotoxin. For both free and total endotoxin, single samples at each of two dilutions were employed. Free endotoxin analysis was discontinued for the field study after eight months of sampling.

SAMPLE COLLECTION

Field Study

Field samples collected within each treatment plant (M1-M5, C1-C5) were collected at sampling locations which plant personnel use for their routine monitoring. Except for a brief period when Concord had a water emergency (January 1981 to July 1981) these points were in continuous operation.

The samples from the chemical mixers (C2) and the sand filters (C4) are from individual parallel units rather than combined samples. Combined sampling was attempted but was found to be impracticable since the hatchways to common channels were located outside and during inclement weather the integrity of the samples could not be assured. Also turbulence caused by submerging the sampling bottle often dislodged any growths from the sides of the channel resulting in a turbid and non-representative sample.

Samples along the distribution systems (M6-M8, C6-C8) were collected from taps which could accommodate the eight liter sampling bottles. Since the taps were not continuously running careful attention was paid to assure that the service main was clear. In addition to wasting water for two to three minutes (APHA, et al., 1981) temperature was monitored. When the temperature ceased dropping and maintained a steady reading the sample was taken.

Temperature, pH, free and total chlorine were analyzed in the field, while all samples for lab analysis were placed in coolers, and iced. Both ice and a foam refrigerant (Koolits, FDC Packaging, Inc., Medfield, MA) were used. Samples were maintained refrigerated until analysis. From the collection of the first sample till all bacteriological samples were incubated was usually about 12-14 hours, with endotoxins, turbidities and perserving the TOC samples about 18-20 hours after collection. When turbidity could not be performed the same day collected, samples were refrigerated and analyzed within 24 hours.

During the study, two changes in sampling stations along the Concord distribution system were made. The Philips 66 Gas Station (C6) disconnected the tap used for sample collection. The sampling station was moved to a Cumberland Farm Store about 100 yards farther along the main. The Apple House (C8) closed for the latter part of the summer of 1981 which necessitated moving the station to Bonny's Flower Shop about midway between the Apple House and the Penacook Fire House (C7), till the fall of 1981.

Pilot Unit Study

Samples of the column effluent were collected by disconnecting a quick disconnect (Figure 3) and inserting the effluent tube through the foil seal on the mouth of the sampling bottle. A sample of column influent was procured from the effluent port of the constant head reservoir. Sampling from the side sampling ports was not performed, since the opening of the ports greatly disturbed both the carbon and the overlying water. temperature, pH,total and free chlorine and dissolved oxygen (DO) were determined as in the field study. The remainder of analyses were performed after transport to the laboratory.

END OF RUN ANALYSIS FOR PILOT UNIT STUDY

Upon the conclusion of each pilot column sampling run the following analyses were performed on each carbon bed. The columns were gradually drained of water to prevent any dislodging of adherent growth. The top and the bottom of each bed (where possible) were collected and placed in a preweighed, sterile container (baked at 180°C overnight).

The samples were transported back to the laboratory where a few grains of carbon from each sample were removed for scanning electron microscope (SEM) examination (see next section), and the drained wet weight for the remainder determined.

Each sample was placed into a blender to which 500ml of sterile dilution water (pH - 7.2) was added. The mixture was blended for one minute and settled for one minute to remove any large carbon particles. Total coliform, acid fast, standard and membrane standard plate counts of the supernantant were determined. In addition to the membrane filter method for total coliforms a procedure using the multiple-tube fermentation method for coliforms was tried. This enabled a much larger volume of water to be filtered then the membrane filter method alone. Approximately 100 ml of sample was filtered. The filter was then placed in a laural tryptose MPN tube, vortexed and incubated as discussed under the MPN procedure for coliforms in Standard Methods (APHA, et al., 1981). Any tubes with gas production were loop transferred to brilliant green bile lactose broth and incubated 24-48 hours. This method was abandoned after consistently giving negative results.

Scanning Electron Microcope (SEM) Examination of Samples

The GAC samples were fixed for SEM analysis by immersion in a formaldehydeglutaraldehyde fixative made up with pH 7.4-7.6 phosphate buffer (Karnovsky, 1965). A postfixation using osmium tetroxide (OsO_4), followed by dehydration in graded ethanol (50, 70, 80, 90, 100%) and overnight storage in amylacetate were performed before drying (Weber, et al., 1978). Drying was performed in a vacuum dessicator. It was found that rinsing with distilled water after the post-fixation step and then drying also gave satisfactory results.

The GAC particles were mounted on aluminum stubs, and sputter coated with gold (45 seconds). A AMR 1000 was used for scanning.

SECTION 4
RESULTS AND DISCUSSION

INTRODUCTION

The field and pilot plant data were computerized using the Rensselaer Polytechnic Institute's IBM 3033. The programs TAXIR (Computing Center, University of Michigan) and MIDAS (Statistical Research Laboratory, University of Michigan) were used for data manipulation and statistical analysis, respectively. Microbial data were log-transformed prior to analysis. The sampling dates were sin-transformed based upon the number of days following the first sampling run that the sample was taken. The sin-transform used was SDATE = sin (# day X $(2\pi/365)$). A cosin-transformation used was CDATE = cosin (# days X $(2\pi/365)$. All other variables are arithmetic. The 0.05 significance level with a coefficient of determination (ρ^2) of 0.5 or greater (correlation coefficient of 0.7 or greater) were used as criteria significance in all determinations.

Total endotoxin was included in regression analysis as an independent variable in the regression equations for the dependent variables SPC, m-SPC, acid-fast and total coliforms, as well as a dependent variable for regressions with the physico-chemical parameters. This was to assess the role of endotoxins in the systems studied. When total endotoxin was used as a variable in the regression analysis, the statistical analysis was first performed without the endotoxin variable. The criteria for acceptance of the regression not only included the ≤ 0.05 significance level and an $\rho^2 \geq 0.5$ but when endotoxin was included as a possible dependent variable, total endotoxin (ENDOT) must have appeared in the equation, for the regression to be considered significant. This was necessary to prevent bias in the regressions selected, since ENDOT data are not available for all sampling locations and dates.

For determining significant stepwise multiple regression the forward stepwise procedure (MIDAS, Statisitical Research Laboratory, University of Michigan) was employed.

ANALYSIS OF FIELD DATA

Scope of Analysis

The following sections are the results and discussion of the physico-chemical and microbial trends through the Manchester and Concord systems.

Discussed are the trends through the treatment facilities and distribution systems as well as the significant seasonal trends for each station over the study period. To satisfy the objectives of the study formal hypotheses were developed from the discussions and statistically tested.

Physico-Chemical and Microbial Trends Through the Manchester and Concord Water Treatment Plants and Distribution Systems

The following section is based upon the mean values calculated for the field data set, which are listed in Tables 7 and 8.

Physico-chemical trends--

The physico-chemical variable, temperature was significantly correlated with SDATE for all stations tested (Table 9). The seasonal trend for temperature approximates a sin curve (Figure 5).

In plant trends--The physico-chemical trends for the Manchester and Concord Water treatment facilities (Figures 6,7,8,9,10 and 11) were as expected given the operation paramenters (Tables 2 and 4) of each facility. Although there seems to be an increase in mean turbidity and TOC through the unused sedimentation basin at Concord (Figures 10 and 11), a pairwise t-test on the data set is not significant at the 0.05 level (Table 10).

Distribution trends--In the Manchester distribution system (M5-M8) temperature and TOC remained unchanged (Figures 7 and 11, respectively, Table 11). As expected both free and total chlorine significantly decreased through the distribution system (Figures 8 and 9, Table 11). The greatest demand was between the finished water (M5) and the first station on the distribution system (M6), which may be an effect of the three day residence time in the covered reservoir. Neither pH nor turbidity exhibited any consistent trend through the system (Figures 6 and 10, respectively).

The most noticeable physico-chemical trend in the Concord distribution system occurred at station C7, the Penacook Fire Station. At this station there was a significantly (pairwise t-test, Table 10) higher mean temperature (Figure 7) than at C6 and C8 which averaged approximately 4°C over the course of the study. C7 was about 2°C higher than at C6 while C7 was approximately 3°C to 5°C higher than C8 over the same period (Figure 12). The winter temperatures at C7 were also higher than at neighboring stations.

The data for Manchester and Concord indicated a decreasing temperature trend as the water progressed through the distribution system, which is found if the distribution temperatures are compared disregarding C7. When collecting the water sample the sampling port was allowed to run for up to ten minutes while monitoring the temperature. The initial temperature would be slightly elevated, as with the other sampling stations, then would establish itself at the constant recorded temperature.

Both free and total chlorine decreased significantly between C6 and C7, while remaining unchanged between C7 and C8 (Figures 8 and 9, respectively, Table 10). Turbidity at station C7 was significantly higher than the surrounding stations (Figure 10, Table 10), and pH was significantly different between C5-C6

TABLE 7. MEANS AND STANDARD ERRORS FOR MANCHESTER

Parameter	Station M1	 M2	 M3	 M4	 M5	 M6	 M7	 M8
pH	6.421 (0.176)	5.959 (0.264)	6.017 (0.257)	5.936 (0.294)	7.157 (0.286)	6.617 (0.633)	6.712 (0.531)	6.439 (0.499)
Temp (^{0}C)	15.778 (7.651)	15.644 (7.808)	16.053 (7.623)	15.778 (7.641)	15.941 (7.716)	16.610 (7.007)	16.510 (6.931)	15.781 (6.671)
CLF (mg/l)	0.002 (0.009)	0.290 (0.207)	0.118 (0.194)	0.000 (---)	1.009 (0.372)	0.489 (0.217)	0.408 (0.169)	0.284 (0.172)
CLT (mg/l)	0.007 (0.041)	0.419 (0.223)	0.237 (0.214)	0.003 (0.018)	1.235 (0.415)	0.621 (0.252)	0.507 (0.178)	0.412 (0.176)
TOC (mg/l)	6.104 (1.305)	4.780 (1.081)	4.623 (1.115)	4.137 (1.803)	3.681 (1.224)	3.551 (0.886)	3.505 (0.923)	3.863 (1.804)
Turb (NTU)	1.060 (1.224)	0.823 (0.274)	0.389 (0.167)	0.418 (0.193)	0.309 (0.209)	0.443 (0.257)	0.319 (0.151)	0.387 (0.276)
LOG[SPC] (CFU/ml)	2.281 (0.766)	0.663 (0.652)	0.553 (0.949)	1.202 (1.059)	0.239 (0.714)	0.057 (0.500)	0.318 (0.675)	0.111 (0.446)
LOG[m-SPC] (CFU/ml)	1.791 (0.927)	0.346 (0.477)	0.075 (0.992)	0.818 (0.805)	-0.442 (0.747)	-0.458 (0.819)	0.531 (0.502)	-0.553 (0.516)
LOG[AF] (CFU/100ml)	-0.323 (0.629)	-0.495 (0.485)	-0.866 (0.547)	-0.972 (0.324)	-0.988 (0.376)	0.964 (0.457)	-0.992 (0.349)	-1.011 (0.537)
LOG[TCOLI] (CFU/100ml)	0.534 (0.497)	-1.025 (0.465)	-1.429 (0.074)	-1.161 (0.278)	-1.482 (*)	-1.482 (*)	0.133 (2.284)	-0.653 (1.657)
Total Endotoxins (μg/l)	8.812 (4.377)	3.462 (3.372)	3.470 (3.424)	3.372 (2.662)	3.683 (3.672)	4.667 (4.667)	4.640 (2.717)	7.523 (10.277)

(   )Standard errors of observations
*only two points, both -1.4815

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TABLE 8. MEANS AND STANDARD ERROR FOR CONCORD

Parameter	Station C1	C2	C3	C4	C5	C6	C7	C8
pH	7.311 (0.375)	10.002 (0.221)	10.084 (0.156)	9.845 (0.457)	9.723 (0.240)	8.578 (0.972)	8.754 (0.825)	8.277 (0.961)
Temp (°C)	17.503 (7.569)	16.875 (7.496)	16.831 (8.045)	16.647 (8.158)	15.559 (6.878)	14.987 (6.827)	18.968 (5.214)	14.078 (6.646)
CLF (mg/1)	0.000 (---)	0.000 (---)	0.000 (---)	0.000 (---)	0.197 (0.862)	0.105 (0.100)	0.008 (0.032)	0.006 (0.029)
CLT (mg/1)	0.000 (---)	0.000 (---)	0.000 (---)	0.000 (---)	0.298 (0.835)	0.237 (0.066)	0.101 (0.064)	0.094 (0.079)
TOC (mg/1)	4.231 (1.106)	4.433 (1.109)	4.705 (1.167)	4.405 (1.284)	4.269 (0.933)	4.361 (1.065)	4.280 (1.087)	4.259 (0.916)
Turb (NTU)	0.826 (0.366)	0.842 (0.499)	0.967 (0.714)	0.621 (0.349)	0.622 (0.383)	0.644 (0.374)	0.823 (0.483)	0.615 (0.324)
LOG[SPC] (CFU/ml)	2.396 (0.499)	2.089 (0.472)	2.379 (0.423)	1.971 (0.483)	0.809 (0.451)	1.244 (0.562)	1.872 (0.694)	1.416 (0.886)
LOG[m-SPC] (CFU/ml)	2.009 (0.562)	1.748 (0.555)	2.110 (0.253)	1.922 (0.582)	0.549 (0.303)	1.077 (0.573)	2.558 (0.494)	1.734 (0.786)
LOG[AF] (CFU/100ml)	-0.425 (0.612)	-0.374 (0.548)	-0.305 (0.626)	-0.745 (0.406)	-0.925 (0.395)	-1.007 (0.321)	-1.075 (0.298)	-0.846 (0.404)
LOG[TCOLI] (CFU/100ml)	0.359 (0.759)	0.334 (1.075)	-0.004 (0.812)	0.097 (0.587)	§	-0.851 (0.891)	§	§
Total Endotoxins (µg/1)	12.204 (5.881)	12.073 (8.304)	13.402 (7.643)	12.225 (6.559)	10.589 (3.791)	9.812 (4.380)	6.290 (6.290)	11.411 (6.452)

( ) Standard errors of observations

§N = 0

TABLE 9. SIGNIFICANT* TWO WAY CORRELATION COEFFICIENTS FOR DATE† FOR CONCORD AND MANCHESTER

Data Set	Variables	Correlation Coefficient	Significance	N
All	SDATE, TEMP	0.911	0.0000	504
All M's	SDATE, TEMP	0.927	0.0000	254
All C's	SDATE, TEMP	0.896	0.0000	250
M5 - M8	SDATE, TEMP	0.903	0.0000	126
	CDATE, LOG[TCOLI]	-0.724	0.0274	9
C5 - C8	SDATE, TEMP	0.830	0.0000	122
C1 - M1	SDATE, TEMP	0.938	0.0000	64
C1	SDATE, TEMP	0.934	0.0000	32
C2	SDATE, TEMP	0.965	0.0000	32
	SDATE, LOG[m-SPC]	0.857	0.0066	8
C3	SDATE, TEMP	0.967	0.0000	32
C4	SDATE, TEMP	0.970	0.0000	32
C5	SDATE, TEMP	0.926	0.0000	32
C6	SDATE, TEMP	0.880	0.0000	32
C7	SDATE, TEMP	0.779	0.0000	31
C8	SDATE, TEMP	0.869	0.0000	27
	SDATE, CLT	-0.707	0.0000	27
M1	SDATE, TEMP	0.954	0.0000	32
M2	SDATE, TEMP	0.951	0.0000	32
M3	SDATE, TEMP	0.950	0.0000	32
M4	SDATE, TEMP	0.946	0.0000	32
M5	SDATE, TEMP	0.948	0.0000	32
M6	SDATE, TEMP	0.904	0.0000	31
M7	SDATE, TEMP	0.903	0.0000	31
M8	SDATE, TEMP	0.854	0.0000	32

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*0.05 level, correlation coefficient ≥ 0.700

†SDATE = sin (# days x $(2\pi/365)$)
CDATE = cosin (# days x $(2\pi/365)$)

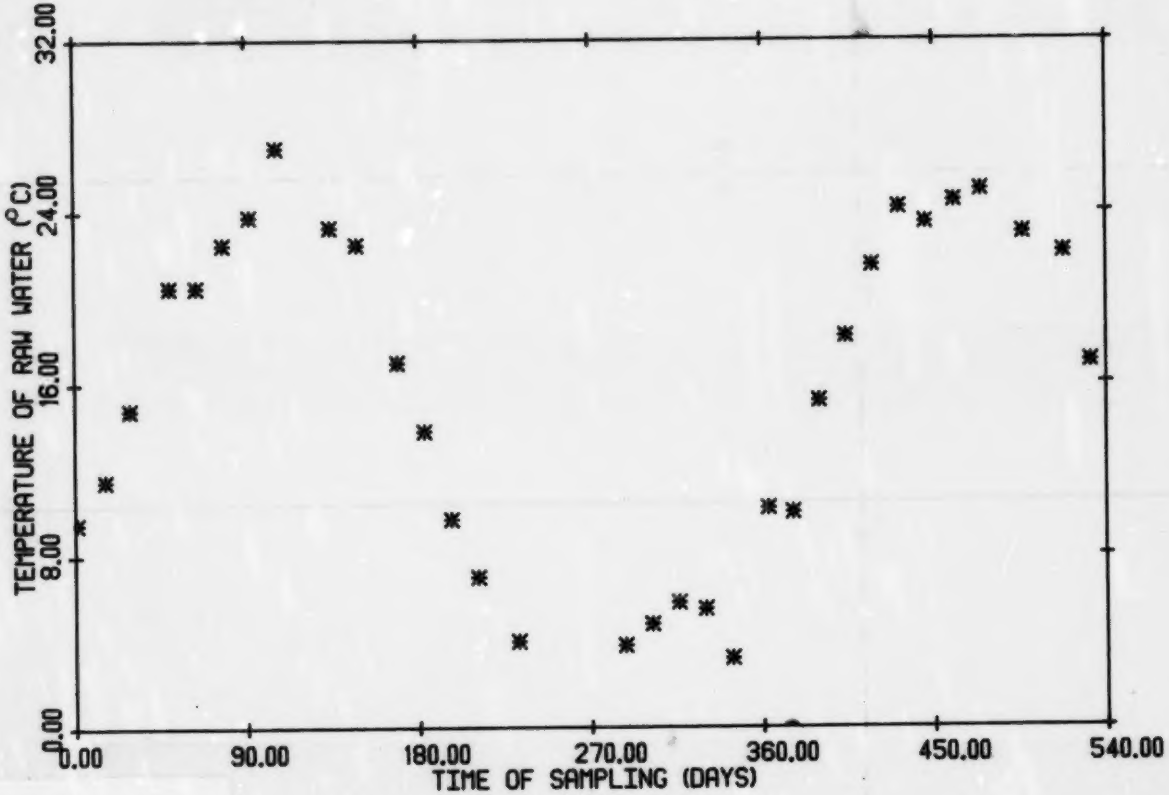


Figure 5. Temperature vs. Date for station M1.
(Day 0 = April 15, 1980)

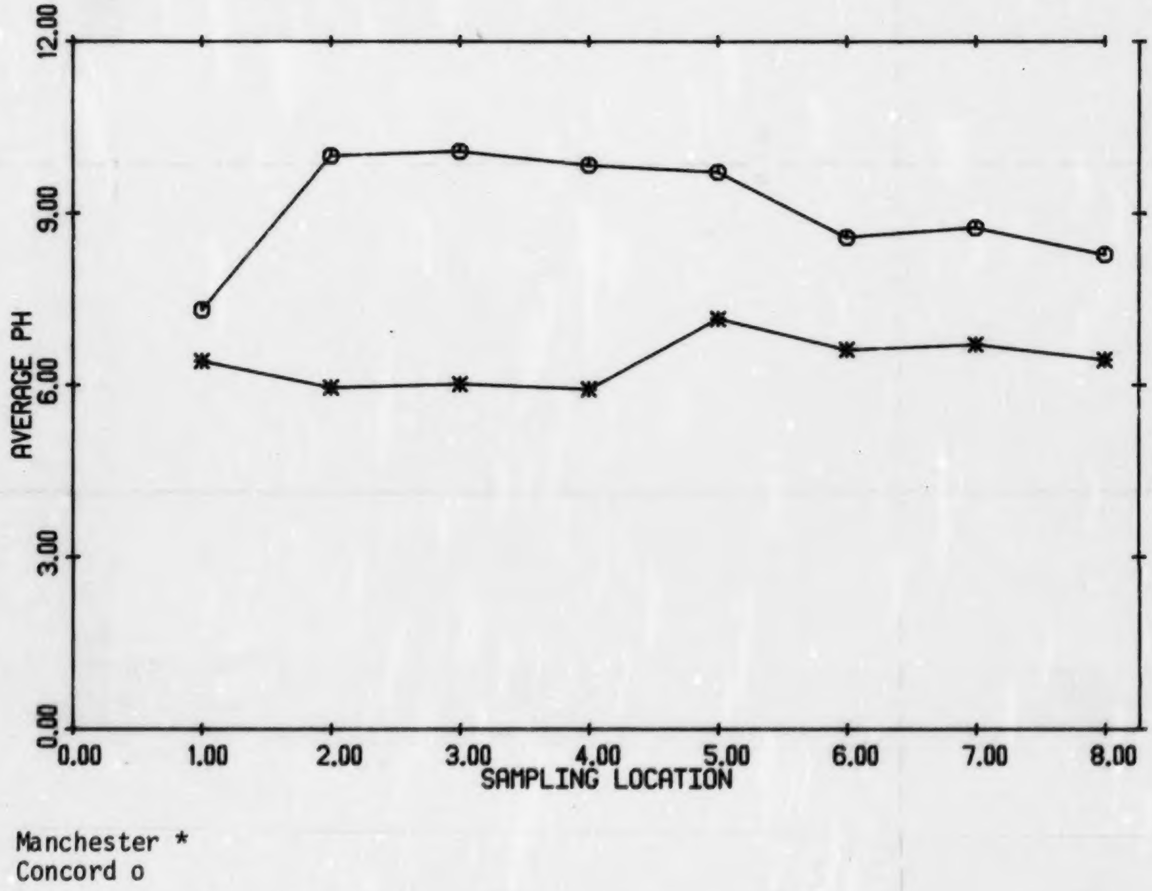


Figure 6. Mean pH vs. station for Manchester and Concord.

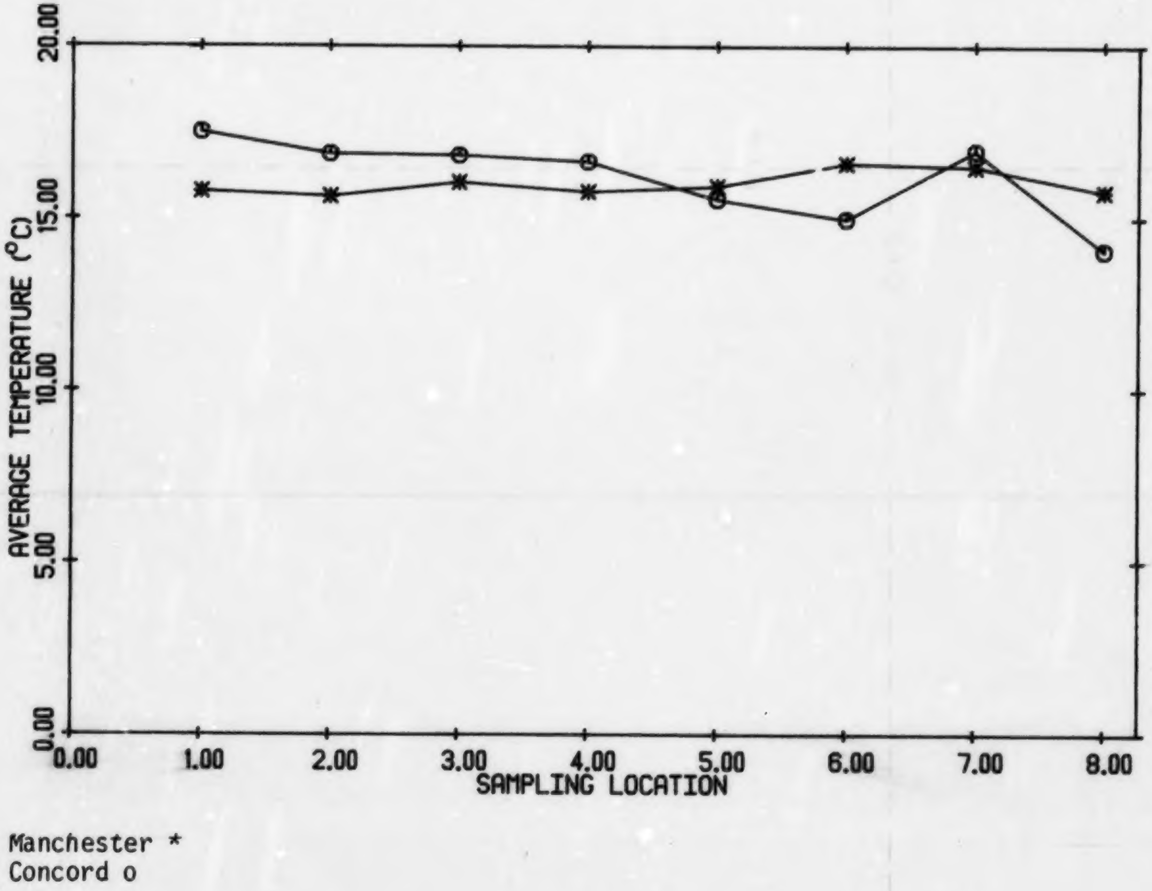


Figure 7. Mean temperature vs. station for Manchester and Concord.

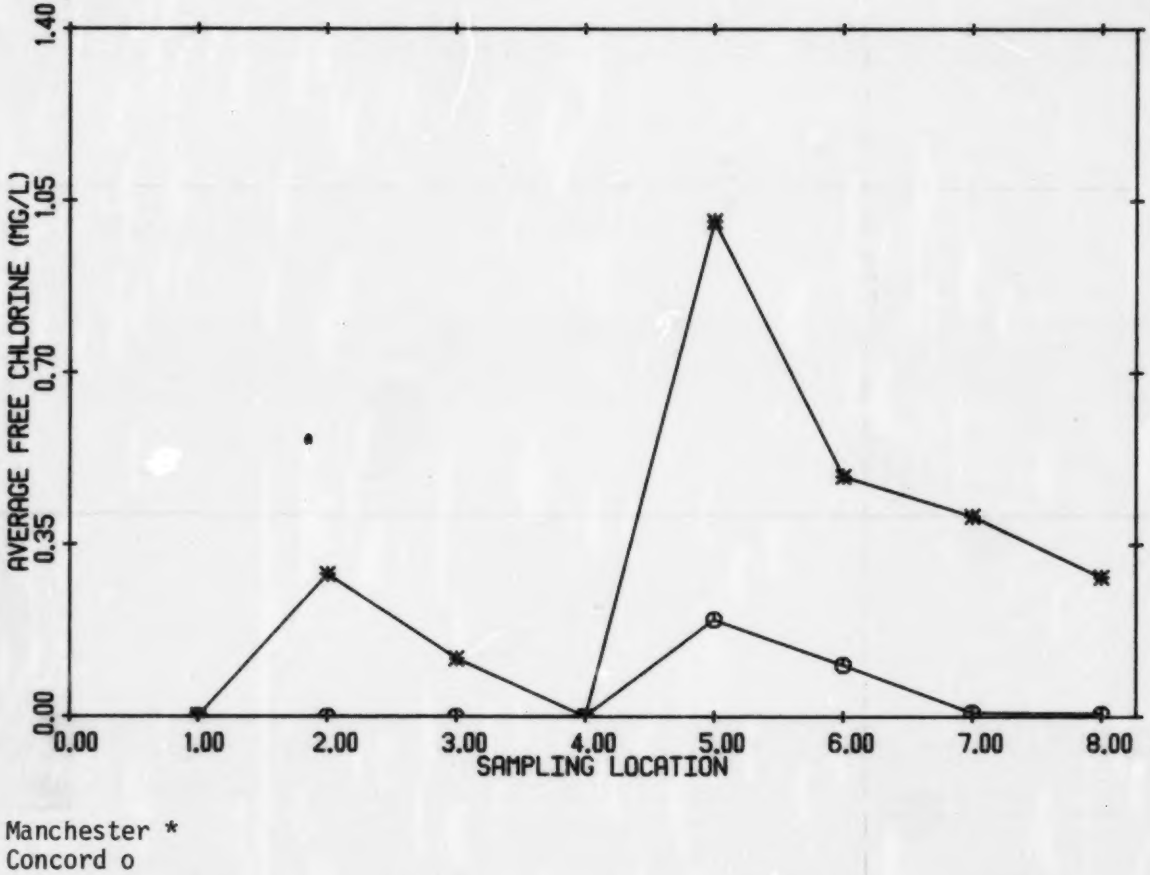


Figure 8. Mean free chlorine vs. station for Manchester and Concord.

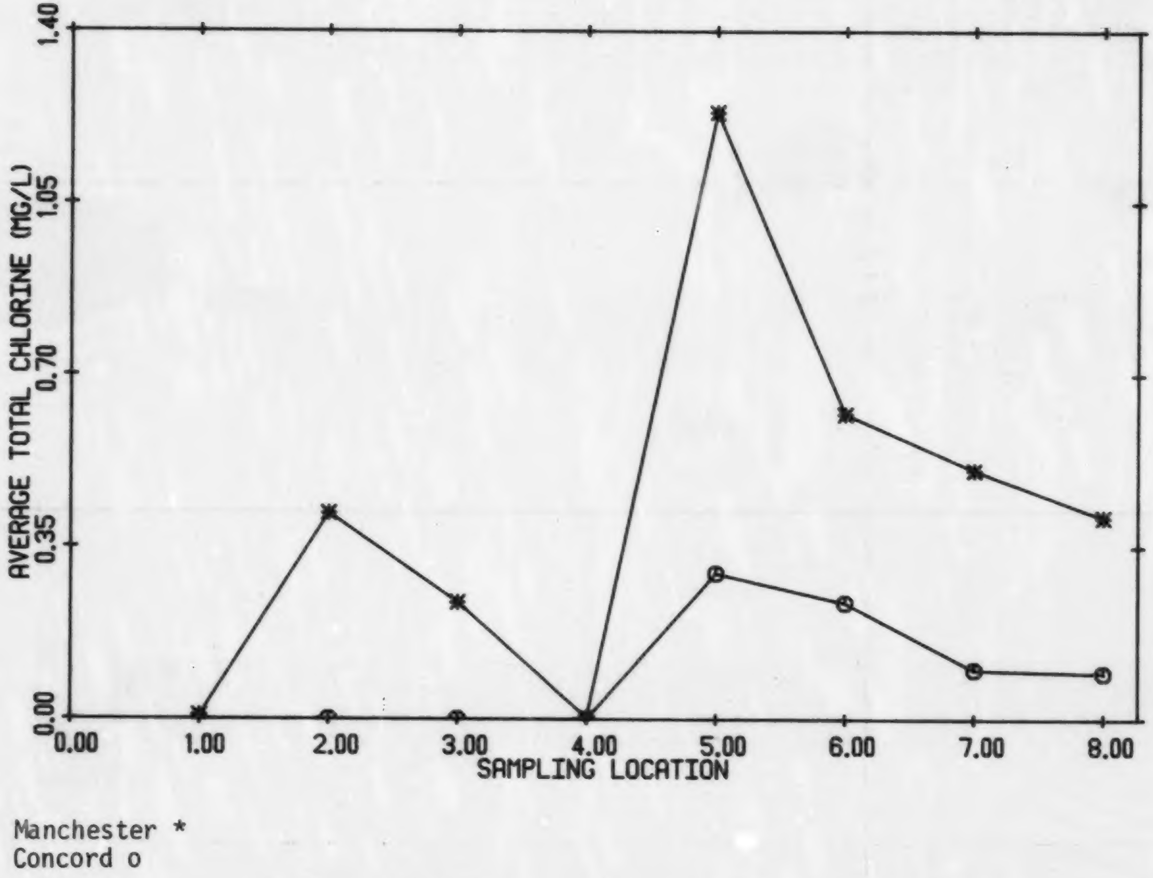


Figure 9. Mean total chlorine vs. station for Manchester and Concord.

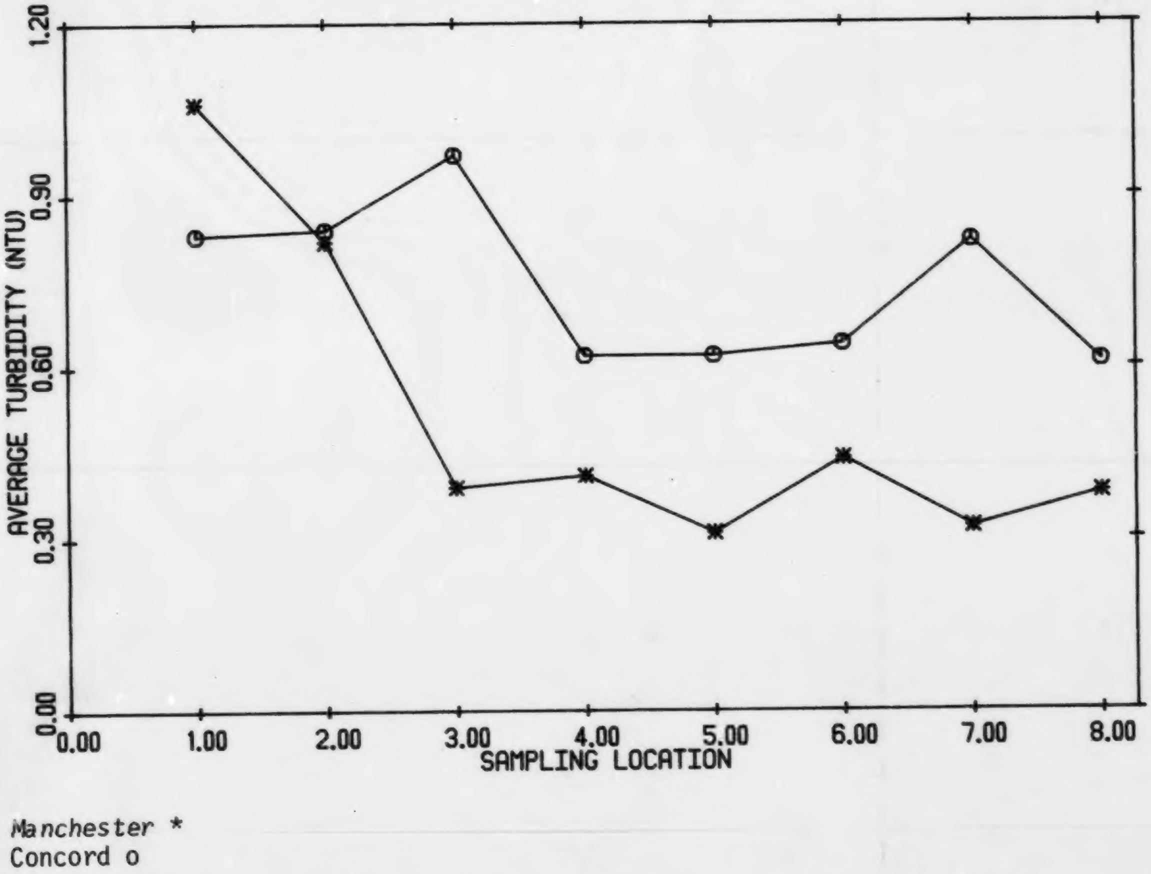
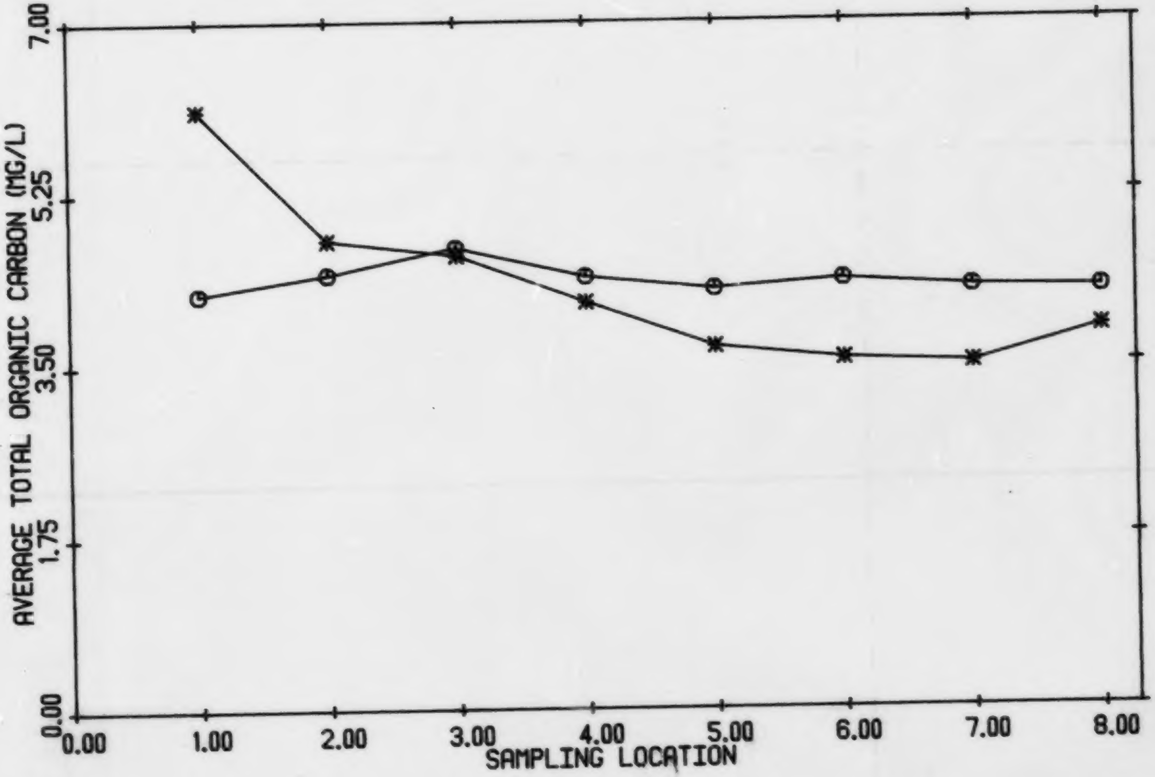


Figure 10. Mean turbidity vs. station for Manchester and Concord.



Manchester *
Concord o

Figure 11. Mean TOC vs. station for Manchester and Concord.

TABLE 10. PAIRWISE t-TEST

Variable	C1-C2 Significance	N	C2-C3 Significance	N	C3-C4 Significance	N	C4-C5 Significance	N	C5-C6 Significance	N	C6-C7 Significance	N	C7-C8 Significance	N
	Comparison Between													
pH	0.0000	32	0.0354	32	0.0027	32	0.0961	32	0.0000	28	0.1720	27	0.0022	22
Temp	0.0167	32	0.8043	32	0.0378	32	0.0305	32	0.1798	32	0.0000	31	0.0000	26
CLF	+	32	+	32	+	32	0.0000	32	0.0000	32	0.0000	31	0.3273	25
CLT	+	32	+	32	+	32	0.0000	32	0.0001	32	0.0000	31	0.7473	26
TOC	0.1932	32	0.1170	32	0.1031	32	0.4884	32	0.4213	32	0.4532	31	0.8851	26
Turb	0.8150	32	0.2930	32	0.0013	32	0.9864	32	0.5819	32	0.0157	31	0.0061	26
LOG[SPC]	0.0016	32	0.0012	31	0.0005	31	0.0000	30	0.0007	31	0.0000	30	0.0051	25
LOG[m-SPC]	*	1	*	1	*	1	+	0	0.0591	2	+	0	+	0
LOG[AF]	0.5023	25	0.8638	23	0.0126	22	0.3135	19	0.3580	18	0.3146	17	0.0355	14
LOG[TCOLI]	0.5480	11	0.6750	12	0.0549	11	+	0	+	0	+	0	+	0
Total Endotoxin	0.9041	22	0.0952	22	0.2083	21	0.2694	19	0.5379	19	0.0453	20	0.8022	16

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* = N=1

+ = N=0

Significance equals $\leq$ 0.05 level

TABLE 11. PAIRWISE t-TEST

Variable	Comparison Between M1-M2 Significance	N	M2-M3 Significance	N	M3-M4 Significance	N	M4-M5 Significance	N	M5-M6 Significance	N	M6-M7 Significance	N	M7-M8 Significance	N
pH	0.0000	32	0.2819	32	0.1237	31	0.0000	31	0.0003	27	0.5116	26	0.0004	27
Temp	0.1493	32	0.0001	32	0.0950	32	0.2373	32	0.2009	31	0.0993	30	0.1418	31
CLF	0.0000	31	0.0000	31	0.0020	31	0.0000	31	0.0000	30	0.0040	29	0.0000	30
CLT	0.0000	31	0.0000	31	0.0000	31	0.0000	31	0.0000	30	0.0008	29	0.0005	30
TOC	0.0000	32	0.1990	32	0.1116	32	0.1369	32	0.5637	31	0.8804	30	0.4027	31
Turb	0.2116	32	0.0000	32	0.4489	32	0.0031	32	0.0044	31	0.0027	30	0.1574	31
LOG[SPC]	0.0000	31	0.2339	27	0.0012	27	0.0006	25	0.3330	20	0.0569	21	0.1787	24
LOG[m-SPC]	0.3810	2	0.0976	3	0.0002	17	0.0580	3	0.1674	2	+	0	0.0245	2
LOG[AF]	0.1268	24	0.0008	19	0.7316	14	0.9599	15	0.5192	17	0.5288	16	0.2926	13
LOG[TCOLI]	0.0736	3	*	1	+	0	*	0	*	1	+	0	+	0
Total Endotoxin	0.0000	21	0.8596	20	0.9995	20	0.5908	21	0.3276	20	0.6181	19	0.2600	19

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* = N=1
+ = N=0
Significance equals ≤ 0.05 level

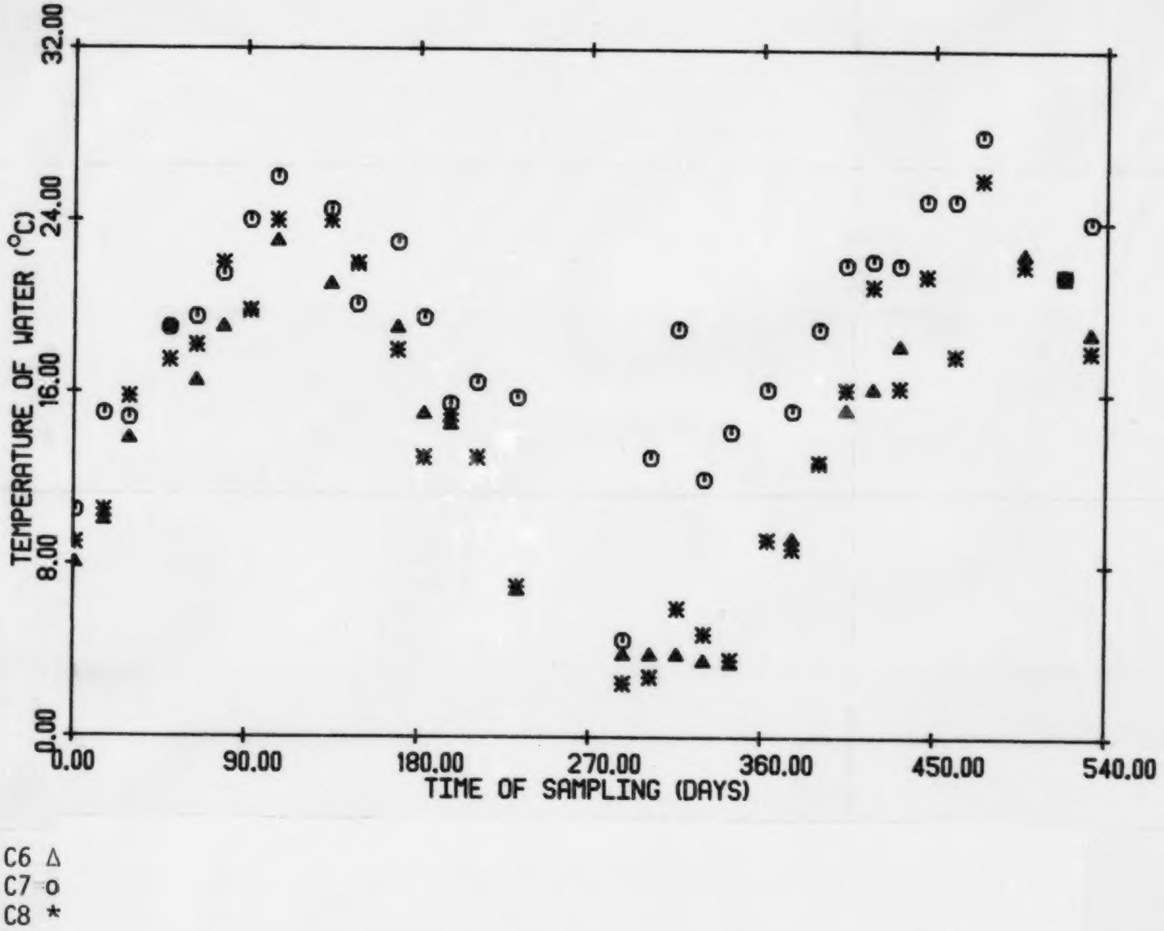


Figure 12. Temperature vs. date for stations C6, C7 and C8.

and C7-C8 (Figure 6, Table 10). TOC remained constant through the system (Figure 11, Table 10).

Microbial trends--

In-plant trends: Manchester--Within the Manchester facility acid-fast organisms exhibited a decreasing trend from the raw water (M1) through the sand filter (M3) (Figure 13) with a significant decline from the prechlorinated effluent station (M2) to the filer effluent (M3) and a further, but statistically insignificant decline through the GAC contactor (M4) (Table 11).

Geometric mean total coliforms are shown in Figure 14. Caution should be observed when interpreting the total coliform data after station M2 since few positive occurrences were recorded (Table 12).

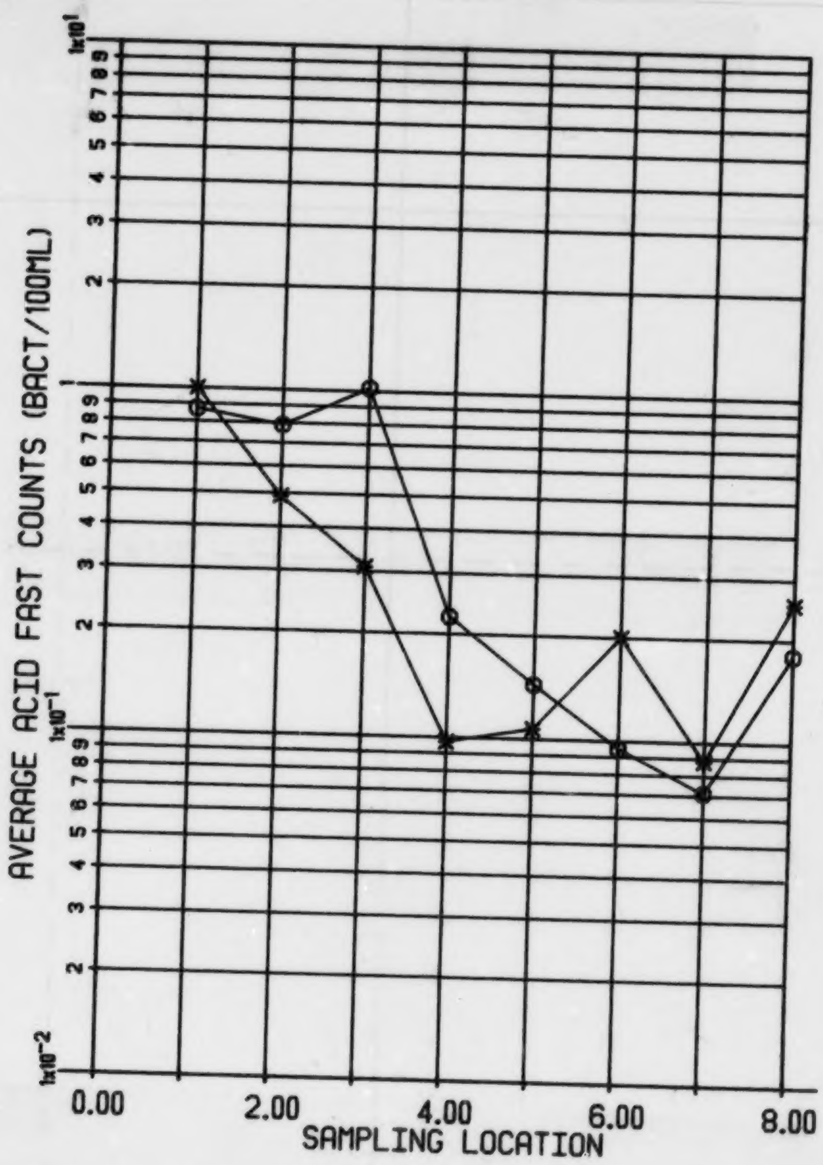
Following a significant decline between the raw water (M1) and the prechlorinated station (M2), total endotoxins remained constant through the remainder of the plant (Figure 15, Table 11).

Standard Plate Count and m-SPC organisms displayed the greatest amount of variability within the Manchester treatment plant. Standard Plate Count decreased significantly after prechlorination (M1 - M2), exhibited a significant increase across the GAC bed (M3-M4) and decreased after chlorination (Figure 16, Table 11). The m-SPC organisms demonstrated the same trends as SPC organisms (Figure 17), but the only significant change occurred across the GAC filter (M3-M4) (Table 11). This could be due to the fewer points available for statistical analysis.

In-plant trends: Concord-- Acid fast organisms demonstrated no significant change from the raw water (C1) through the sedimentation basin (C3), but as in the case of Manchester, exhibited a significant decline of organisms through the sand filter (C4) (Figure 13, Table 10).

Total endotoxin in the Concord treatment plant appeared much higher than in Manchester (Figure 15). Using the paired t-test between successive stations, no significant difference was indicated through Concord (Table 10), although a decreasing trend for the means was noted.

As in the Manchester facility, SPC and m-SPC organisms at Concord displayed the greatest amount of variance of the micro-organisms studied (Figures 16 and 17, Table 10). There was a significant decrease of organisms through the flash mixers used for pH adjustment and permanganate addition (C2) followed by a significant increase through the sedimentation tanks (C3). A 60% reduction in the number of SPC organisms occurred through the sand filter (between C3 and C4). This was not surprising due to the decrease



Manchester *
Concord o

Figure 13. Mean acid-fast vs. station for Manchester and Concord.

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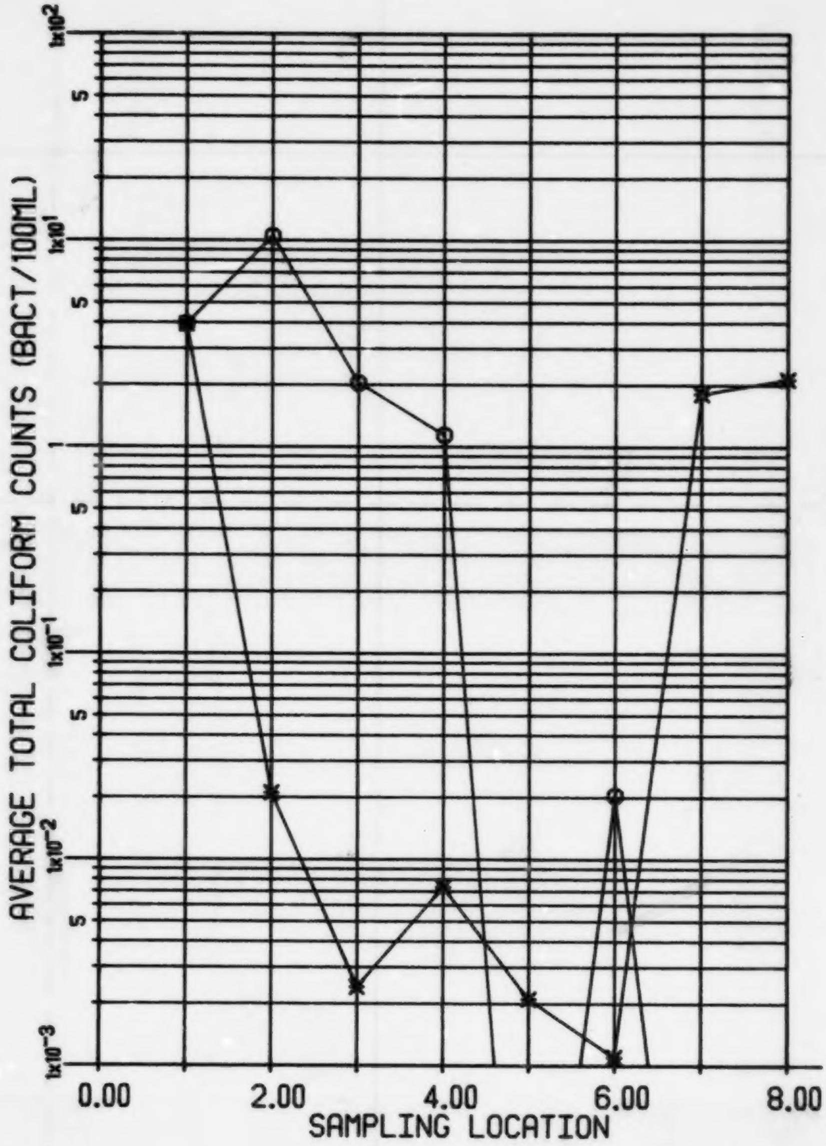

Manchester *
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Figure 14. Mean total coliform vs. station for Manchester and Concord.

TABLE 12. TOTAL COLIFORMS AND CORRESPONDING PHYSICO-CHEMICAL PARAMETERS FOUND IN THE MANCHESTER DISTRIBUTION SYSTEM

Data Set	Day	Date	pH	Temperature (^oC)	Free Chlorine (mg/l)	Total Chlorine (mg/l)	Turbidity (NTU)	TOC (mg/l)	Total Coliform (CFU/100ml)
M5	0	04/15/80	6.89	9.8	0.85	1.10	0.43	4.12	0.033
	49	06/03/80	7.65	20.3	0.78	0.85	0.25	6.28	
M6	49	06/03/80	6.70	18.5	0.51	0.58	0.20	4.60	0.033
M7	403	05/26/81	6.63	16.8	0.00	0.18	0.25	3.40	0.033
	531	09/29/81	7.10	19.0	0.60	0.70	0.23	3.50	56.000
M8	15	04/30/80	4.80	11.0	0.15	0.25	0.75	2.92	0.033
	28	05/13/80	5.90	12.5		0.30	0.25	8.80	
	147	09/09/80	6.20	23.3	0.20	0.28	0.30	6.00	68.000
	182	10/14/80	6.60	18.0	0.35	0.50	0.40	3.32	0.033

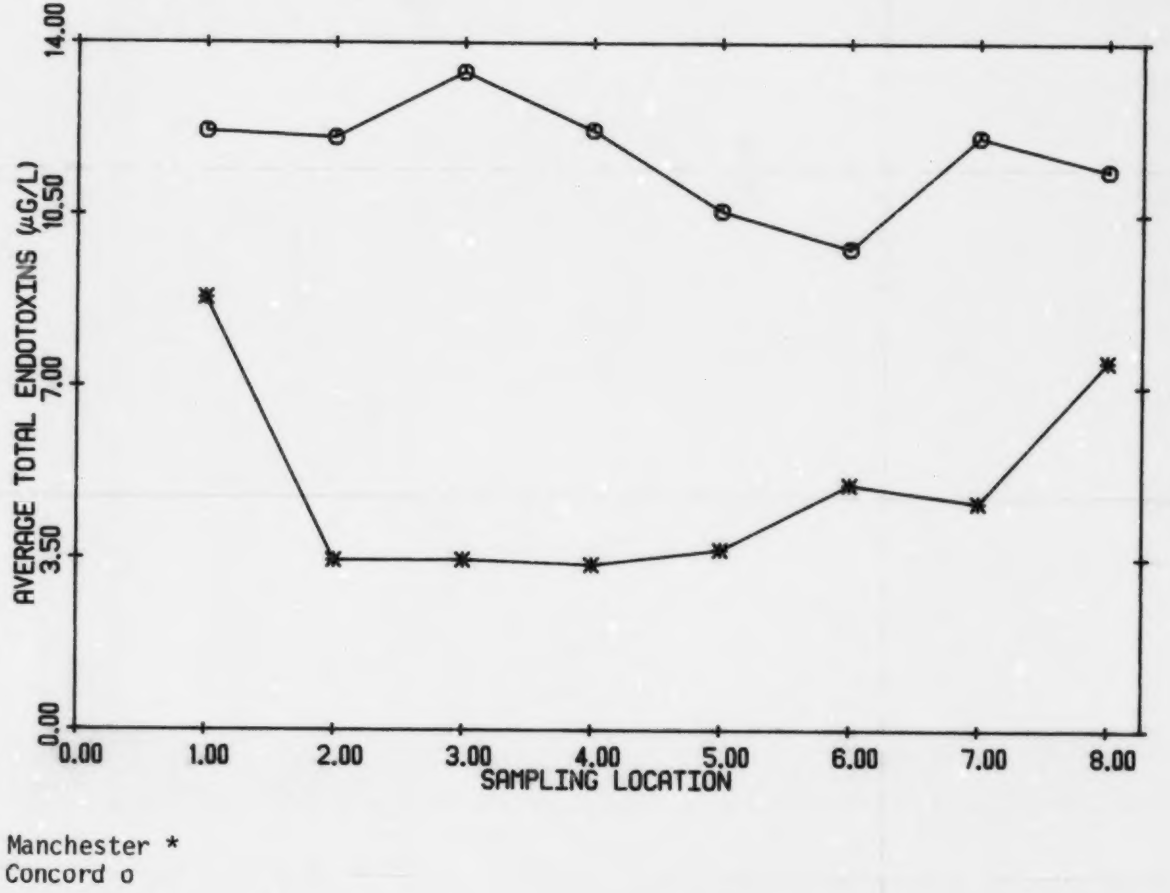

Figure 15. Mean total endotoxin vs. station for Manchester and Concord.

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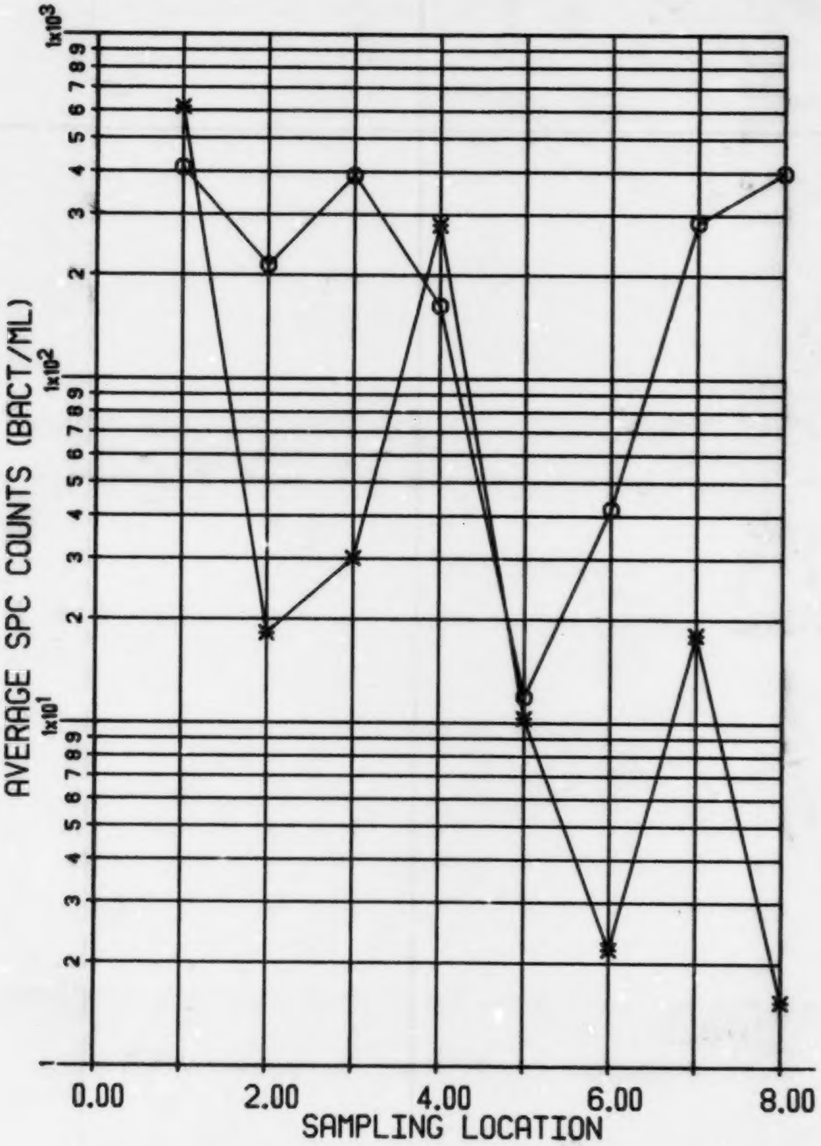
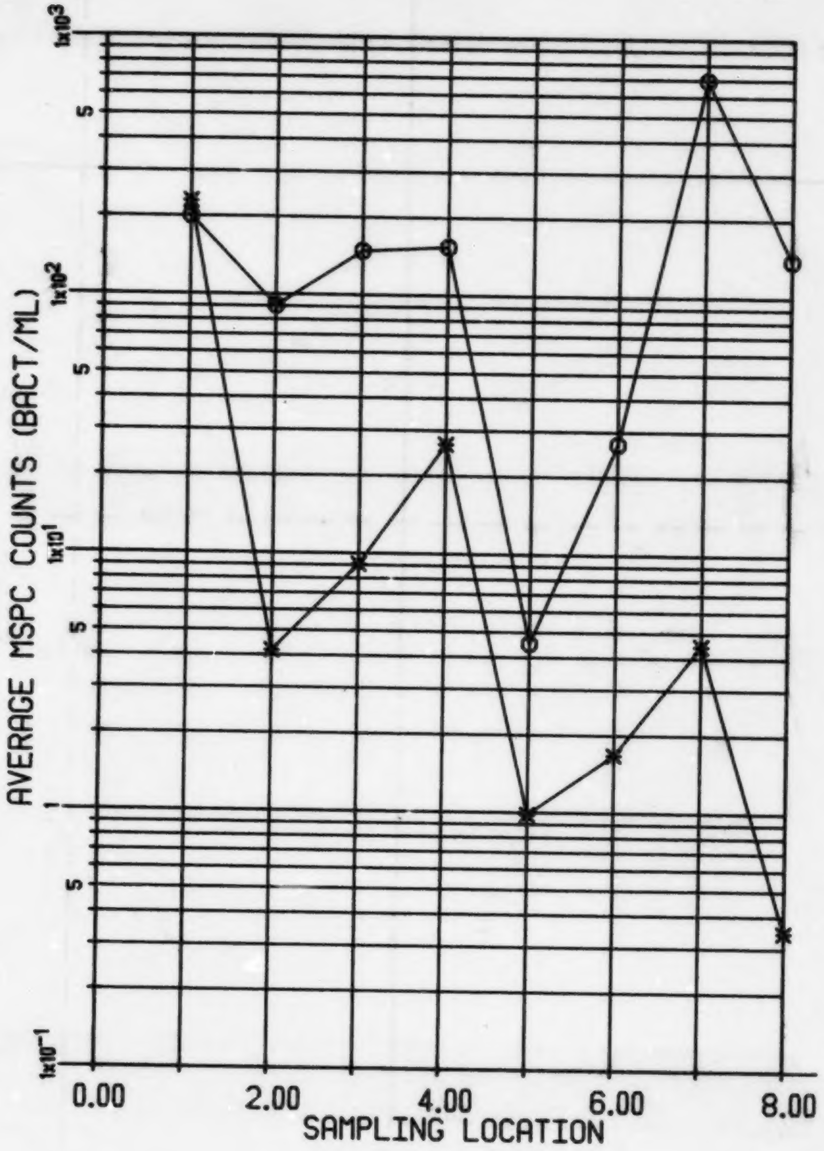


Manchester *
Concord o

Figure 16. Mean SPC vs. station for Manchester and Concord.



Manchester *
Concord o

Figure 17. Mean m-SPC vs. station for Manchester and Concord.

in the average turbidity through the filter. Post-chlorination resulted in over one log reduction of organisms (C5). Even though SPC organisms tended to be higher than m-SPC organisms through the Concord facility, the percent reductions calculated from the mean values agreed closely. The total reduction in SPC (raw water minus finished water) was 99.1% for Manchester and 97.4% for Concord. The percent reduction due to post-chlorination (M4 minus M5, C4 minus C5) was 89.3%, respectively.

The m-SPC trend very closely followed the SPC trend, but due to the low number of paired observations, no analyses of the differences between successive stations were performed.

At C2, m-SPC was correlated with SDATE (Table 9). However, this observation was not noted at any other stations, and thus may be of limited applicability.

Distribution trends: Manchester-- Acid-fast organisms exhibited no significant change through the distribution system, maintaining a level of approximately 0.1 CFU/100 ml (Figure 13, Table 11).

Total coliforms gave positive counts at M5 (0.03 CFU/100 ml; N = 2), M6 (0.03 CFU/100 ml; N = 2), M7 (1.36 CFU/100 ml; N = 2) and M8 (0.22 CFU/100 ml; N - 4) (Figure 14, Table 7). This was out of the total of 32 sampling trips. Table 12 shows the positive total coliform counts by date and the corresponding values for pH, temperature, free and total chlorine, turbidity and TOC.

It is obvious from the above data, that a major reason for finding coliforms was the filtration of one liter of sample rather than the 100 ml normally used in the coliform analysis (APHA, et al.. 1981). The observations suggest incresed counts at M7, the South Mainstreet Fire Station, but no t-test could be computed due to the scarcity of positive counts. Total coliform appears to be negatively correlated to CDATE, which might indicate a lag effect for growth in the system (Table 9).

There was no significant change in total endotoxins in the distribution system (Table 11). The increasing trend indicated by the means is obscured by the large standard errors (Figure 15, Table 7).

As with the in-plant data, the distribution system data for SPC and m-SPC displayed the same trend with greater variation within the distribution system (Figures 16 and 17). Standard Plate Count exhibited no significant change between the finished water (M5) and the first station on the distribution system (M6). This was also true for m-SPC (Table 11). A noticeable change occurred with regard to station M7 (South Main Street Fire House) for both SPC and m-SPC. There was a significant increase in SPC organisms between the first distribution station (M6) and the fire station (M7) possibly due to high volume usage and resultant shearing from pipe walls. The counts then remained steady to the third distrubution station (M8). Although the increasing trend of m-SPC organisms is not significant, the decrease from M7 to M8 is (Table 11).

Distribution trends: Concord--No significant changes were exhibited by acid-fast organisms through the distribution system (Figure 13, Table 10). As at Manchester acid-fast densities averaged 0.1 - 0.2 CFU/100ml (Figure 13).

No total coliforms were recorded in the finished water (C5), the second station on the distribution system (C7) and the third station on the system (C8). On two occasions confirmed counts were found at the first distribution station (C6) at an average level of 0.14 CFU/100 ml (Figure 14).

Total endotoxin showed no significant change between C5-C6. A significant decrease occurred between C6 and C7 (the Penacook Fire Station). Although there appears to be a trend towards increased total endotoxin in the end of the distribution system, a pairwise t-test shows no significant difference between the two stations (Figure 15, Table 10).

As in the Manchester distribution system, the SPC and m-SPC data displayed the same mean trend pattern (Figure 16 and 17). Standard Plate Count organisms were significantly different between adjacent stations (Table 10). They increased between C5 - C6 and C6 - C7 with a decreasing trend between C7 - C8.

The mean trends for m-SPC increased between C5 - C6, increased above the level of SPC for C7 and decreased from C7 to C8. Due to the number of paired observations, the paired t-test was only calculated for C5 -C6 which showed the increase to be significant.

Hypotheses Tested

Nine formal hypotheses were developed to test against the data base. They are as follows:

1. Raw water quality at Manchester is different than at Concord
2. Treated water quality (microbial) at Manchester is different than at Concord.
3. Various indicators (total coliform, acid-fast, standard plate count, endotoxin, m-SPC) are correlated.
4. The water quality (microbial) at each point is dependent upon physico-chemical conditions.
5. The change in bacterial quality between two successive points is dependent on the physico-chemical characteristics existing between them.
6. Chlorine residuals are inversely related to microbial concentrations.
7. Microbial quality is altered upon passage through the carbon bed.
8. Endotoxin levels provide a good estimate of indicator organisms in raw, partially treated and finished water.

9. m-SPC is a good estimator of SPC in raw, partially treated and finished water.

Hypothesis 1. Raw water quality at Manchester is different than at Concord

A pairwise t-test was performed between the raw water at Manchester (M1) and Concord (C1) (Table 13). The statistic indicates that there is no significant difference between the raw water variables SPC, m-SPC, acid-fast, total coliform and turbidity. There is a statistical difference between total endotoxin, pH, temperature and TOC between the plants.

Hypothesis 2. Treated water quality (microbial) at Manchester is different than Concord.

Pairwise t-test were performed for the finished water and the correspondingly numbered sampling sites in the distribution systems of Manchester and Concord (Tables 14, 15, 16 and 17).

Except for temperature at M5 -C5 (Table 14) and TOC at M8 - C8 (Table 17) the physico-chemical parameters appear statistically different in the treated water from the two plants. This could be expected since the treatment sequence at each plant is different. (Tables 1 and 3).

There appears to be no difference in acid-fast organisms between the two systems nor in m-SPC between M6 and C6 (Table 15) and total endotoxin between M8 and C8 (Table 17). These results should be tempered with some reservation due to the difference in residence times for the water at each corresponding point.

Hypothesis 3. Various indicators (total coliform, acid-fast, standard plate count, endotoxin and m-standard plate count) are correlated--

Most notable when reviewing the significant correlation coefficients (Table 18) is the frequency that SPC and m-SPC appear. They appear positively correlated for all stations pooled, Concord and Manchester alone, and the raw waters combined, C1, C6, M1, M2, M3, M4, M6. For a more detailed account of the relationship between m-SPC and SPC see the discussion under Hypothesis 9.

Total coliform counts are significantly correlated with acid-fast organisms in the raw water at Manchester (M1) while m-SPC is correlated to total coliforms for the raw waters combined (M1 , C1), Table 18 and 19.

Hypothesis 4. The water quality (microbial) at each point is dependent upon physico-chemical conditions.

Endotoxins will not be examined in the following subsections as an independent variable as it is discussed under Hypothsis 8.

Standard Plate Count-- Standard Plate count organisms do not seem to be correlated with TOC (Table 18). Only one coefficient for TOC is significant in the multiple regression equations which appears to contribute very little to the overall equation (Table 20). Although TOC appears in the significant stepwise regression equation for all the data combined, its low coefficient indicates it contributes little to the overall equation (Table 21).

TABLE 13. PAIRWISE t-TEST COMPARING RAW WATER QUALITY FOR MANCHESTER AND CONCORD

Variable	Mean	Significance	N
SPC	2.281[a] 2.396[b]	0.228	32
m-SPC	2.059[a] 1.892[b]	0.423	3
ACID-FAST	0.267[a] - 0.381[b]	0.311	24
TOTAL COLIFORM	0.485[a] 0.549[b]	0.750	11
TOTAL ENDOTOXIN	8.812[a] 12.490[b]	0.015*	21
pH	6.421[a] 7.311[b]	0.000*	32
TEMPERATURE	15.778[a] 17.503[b]	0.000*	32
TURBIDITY	1.060[a] 0.826[b]	0.273	32
TOC	6.104[a] 4.231[b]	0.000*	32

---

[a] Manchester

[b] Concord

* Significant at 0.05 level

TABLE 14 . PAIRWISE t-TEST COMPARING FINISHED WATER QUALITY (M5 AND C5) FOR MANCHESTER AND CONCORD

Variable	Mean	Significance	N
SPC	0.249[a] 0.789[b]	0.0012*	24
m-SPC	0.107[a] 0.624[b]	0.0133*	4
ACID-FAST	- 0.977[a] - 0.957[b]	0.8719	18
TOTAL COLIFORM	N = 0		
TOTAL ENDOTOXIN	3.976[a] 10.589[b]	0.0000*	19
pH	7.157[a] 9.723[b]	0.0000*	32
TEMPERATURE	15.941[a] 15.559[b]	0.3347	32
FREE CHLORINE	1.009[a] 0.197[b]	0.0000*	31
TOTAL CHLORINE	1.235[a] 0.299[b]	0.0000*	31
TURBIDITY	0.309[a] 0.622[b]	0.0001*	32
TOC	3.681[a] 4.269[b]	0.0055*	32

---

[a] Manchester

[b] Concord

*Significant at 0.05 level

TABLE 15. PAIRWISE t-TEST COMPARING WATER QUALITY AT M6 AND C6 FOR MANCHESTER AND CONCORD

Variable	Mean	Significance	N
SPC	0.057[a] 1.139[b]	0.0000*	23
m-SPC	- 0.439[a] 0.875	0.0524	5
ACID-FAST	- 1.042[a] - 1.023[b]	0.8767	17
TOTAL COLIFORM	N = 0		
TOTAL ENDOTOXIN	5.010[a] 9.728[b]	0.0037*	20
pH	6.606[a] 8.555[b]	0.0000*	26
TEMPERATURE	16.610[a] 15.052[b]	0.0002*	31
FREE CHLORINE	0.489[a] 0.106[b]	0.0000*	30
TOTAL CHLORINE	0.621[a] 0.239[b]	0.0000*	30
TURBIDITY	0.443[a] 0.617[b]	0.0105*	31
TOC	3.551[a] 4.330[b]	0.0000*	31

---

[a] Manchester

[b] Concord

* Significant at 0.05 level

TABLE 16. PAIRWISE t-TEST COMPARING WATER QUALITY AT M7 and C7 FOR MANCHESTER AND CONCORD

Variable	Mean	Significance	N
SPC	0.325[a] 1.891[b]	0.0000*	29
m-SPC	0.837[a] 2.797	0.0607*	3
ACID-FAST	- 0.984[a] - 1.099[b]	0.1387	15
TOTAL COLIFORM	N = 0		
TOTAL ENDOTOXIN	4.642[a] 12.178[b]	0.0002*	19
pH	6.689[a] 8.797[b]	0.0000*	26
TEMPERATURE	16.293[a] 19.450[b]	0.0001*	30
FREE CHLORINE	0.398[a] 0.009[b]	0.0000*	29
TOTAL CHLORINE	0.497[a] 0.098[b]	0.0000*	29
TURBIDITY	0.323[a] 0.830[b]	0.0000*	30
TOC	3.532[a] 4.189[b]	0.0012*	30

---

[a] Manchester

[b] Concord

*Significant at 0.05 level

TABLE 17. PAIRWISE t-TEST COMPARING WATER QUALITY AT M8 AND C8 FOR MANCHESTER AND CONCORD

Variable	Mean	Significance	N
SPC	0.739[a] 1.569[b]	0.0000*	20
m-SPC	- 0.886[a] 2.477[b]		1
ACID-FAST	- 0.936[a] - 0.905[b]	0.867	12
TOTAL COLIFORM	N = 0		
TOTAL ENDOTOXIN	7.938[a] 11.830[b]	0.193	16
pH	6.375[a] 8.277[b]	0.0000*	23
TEMPERATURE	15.267[a] 14.078[b]	0.0000*	27
FREE CHLORINE	0.272[a] 0.006[b]	0.0000*	25
TOTAL CHLORINE	0.402[a] 0.095[b]	0.0000*	26
TURBIDITY	0.417[a] 0.615[b]	0.0005*	27
TOC	3.954[a] 4.259[b]	0.469	27

---

[a] Manchester

[b] Concord

*Significant at 0.05 level

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TABLE 18. SIGNIFICANT* TWO WAY CORRELATION COEFFICIENTS FOR CONCORD AND MANCHESTER

Data Set	Variables	Correlation Coefficient	Significance	N
All	CLF, CLT	0.964	0.0000	495
	LOG[SPC], LOG[m-SPC]	0.854	0.0000	129
All M's	CLF, CLT	0.963	0.0000	246
	LOG[SPC], LOG[m-SPC]	0.802	0.0000	76
All C's	CLF, CLT	0.836	0.0000	249
	LOG[SPC], LOG[m-SPC]	0.789	0.0000	53
M5 - M8	CLF, CLT	0.942	0.0000	122
C5 - C8	CLF, CLT	0.816	0.0000	122
	LOG[SPC], LOG[m-SPC]	0.841	0.0000	26
C1, M1	LOG[SPC], LOG[m-SPC]	0.873	0.0005	11
	LOG[m-SPC], LOG[TCOLI]	0.818	0.0245	7
C2	TEMP, LOG[m-SPC]	0.782	0.0220	8
C5	CLF, CLT	0.734	0.0000	32
C6	CLF, LOG[m-SPC]	0.7312	0.0393	8
	LOG[SPC], LOG[m-SPC]	0.9418	0.0005	8
C8	TEMP, TURB	-0.724	0.0000	27
M1	CLF, CLT‡	1.000	0.	31
	TOC, LOG[m-SPC]	-0.939	0.0180	5
	LOG[SPC], LOG[m-SPC]	0.967	0.0073	5
	LOG[AF], LOG[TCOLI]	0.751	0.0005	17
M2	CLF, CLT	0.941	0.0000	31
	LOG[SPC], LOG[m-SPC]	0.778	0.0135	9
M3	CLF, CLT	0.893	0.0000	31
	LOG[SPC], LOG[m-SPC]	0.865	0.0000	16
M4	TEMP, LOG[SPC]	0.705	0.0000	32
	TOC, LOG[TCOLI]	-0.998	0.0388	3
	LOG[SPC], LOG[m-SPC]	0.849	0.0000	26
M5	CLF, CLT	0.823	0.0000	31
M6	CLF, CLT	0.905	0.0000	30
	LOG[SPC], LOG[m-SPC]	0.757	0.0490	7
M7	CLF, CLT	0.936	0.0000	30
M8	CLF, CLT	0.937	0.0000	31
	CLT, LOG[m-SPC]	-0.879	0.0496	5
	TOC, LOG[m-SPC]	0.917	0.0285	5

---

*0.05 level, correlation coefficient > 0.700

‡Almost all samples 0 (see text)

TABLE 19. SIGNIFICANT CORRELATED MICROBIAL INDICATORS

Station	Dependent Variable	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
M1	LOG[TCOLI] =	0.595 + 0.516 LOG[AF]	0.751	0.564	0.0005	17
M1, C1	LOG[m-SPC] =	1.265 + 0.968 LOG[TCOLI]	0.818	0.669	0.0047	7

---

†Correlation equations between log[SPC] and log[m-SPC] on Table 31.

TABLE 20. SIGNIFICANT† MULTIPLE LINEAR REGRESSION EQUATIONS BETWEEN LOG[SPC] AND PHYSICO-CHEMICAL PARAMETERS FOR FIELD DATA

Data Set	Dependent Variable		Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[SPC]	=	-0.127 + 0.091 pH* + 0.009 TEMP + 1.395 CLF* -2.437 CLT* + 0.409 TURB* + 0.091 TOC* +0.348 SDATE - 0.107 CDATE + 0.024 ENDOT*	0.717	0.514	0.0000	283
Concord Only	LOG[SPC]	=	3.052* - 0.063 pH - 0.020 TEMP + 2.009 CLF* -5.125 CLT* + 0.273 TURB* - 0.094 TOC +0.475 SDATE* - 0.049 CDATE + 0.009 ENDOT	0.725	0.526	0.0000	153
M2	LOG[SPC]	=	0.345 - 0.285 pH + 0.136 TEMP + 7.785 CLF* -8.472 CLT* + 1.419 TURB + 0.380 TOC -1.256 SDATE + 0.358 CDATE + 0.035 ENDOT	0.873	0.762	0.0301	20
M3	LOG[SPC]	=	6.914 - 0.923 pH + 0.023 TEMP + 8.947 CLF* -9.334 CLT* - 1.293 TURB + 0.636 TOC + 0.011 ENDOT	0.875	0.765	0.0427	16
C6	LOG[SPC]	=	1.529 - 0.052 pH - 0.039 TEMP + 1.340 CLF -1.843 CLT + 0.515 TURB* + 0.099 TOC +1.303 SDATE + 0.023 CDATE + 0.016 ENDOT	0.939	0.881	0.0032	19

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†0.05 level, multiple correlation coefficient $\geq$ 0.700

*significant variables at the 0.05 level

TABLE 21. SIGNIFICANT* STEPWISE MULTIPLE LINEAR REGRESSION EQUATIONS BETWEEN MICROBIAL NUMBERS AND PHYSICO-CHEMICAL PARAMETERS†

Data Set	Dependent Variable	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[SPC]	= -0.526 + 0.091 pH + 0.039 TEMP + 1.487 CLF - 2.495 CLT + 0.097 TOC + 0.395 TURB + 0.022 ENDOT	0.712	0.507	0.0000	283
	LOG[m-SPC]	= -0.977 + 0.227 pH - 1.601 CLT + 0.532 TURB + 0.742 SDATE - 0.209 CDATE	0.785	0.616	0.0000	128
Concord Only	LOG[m-SPC]	= 4.669 - 3.076 CLT - 0.432 TOC - 0.082 ENDOT	0.828	0.685	0.0042	15
M5-M8	LOG[TCOLI]	= -0.466 - 1.178 CDATE	0.724	0.524	0.0274	9
C5-C8	LOG[m-SPC]	= 0.571 - 0.085 TEMP - 3.555 CLT	0.749	0.561	0.0003	23
M3, M4	LOG[m-SPC]	= -0.065 + 0.060 TEMP + 6.409 CLF - 6.833 CLT	0.749	0.561	0.0000	43
M1	LOG[SPC]	= 1.434 + 0.056 TEMP - 0.362 CDATE	0.725	0.526	0.0000	31
	LOG[m-SPC]	= 5.757 - 0.649 TOC	0.939	0.881	0.0180	5
M4	LOG[SPC]	= -0.233 + 0.093 TEMP	0.718	0.515	0.0000	30
	LOG[TCOLI]	= -0.839 - 0.053 TOC	0.998	0.996	0.0388	3
M7	LOG[m-SPC]	= 0.628 + 0.838 CDATE	0.983	0.996	0.0171	4
M8	LOG[m-SPC]	= -2.014 + 0.387 TOC	0.998	0.997	0.0327	3
C2	LOG[m-SPC]	= 1.572 + 0.701 SDATE	0.857	0.734	0.0066	8
C4	LOG[AF]	= -1.832 + 0.676 TURB + 0.121 TOC + 0.489 SDATE	0.738	0.544	0.0011	24
	LOG[TCOLI]	= -0.579 - 0.610 CDATE + 0.047 ENDOT	0.839	0.705	0.0139	10
C6	LOG[m-SPC]	= 0.475 + 5.284 CLF	0.909	0.827	0.0045	7
C8	LOG[m-SPC]	= 0.692 + 1.195 SDATE	0.999	0.999	0.0157	3
	ENDOT	= 3.021 + 11.059 TURB	0.748	0.559	0.0033	13

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*0.05 level, multiple correlation coefficient $\geq$ 0.700

†possible parameters: pH, TEMP, CLF, CLT, TURB, TOC, SDATE, CDATE, ENDOT

There are no significant two way correlations between SPC and free or total chlorine (Table 18). In the multiple regression equations for all data combined, Concord only, M2, and M3, in which free and total chlorine are significant, the coefficient for free chlorine exhibits a positive sign, while total chlorine a negative, with the coefficients for the chlorine variables being the highest (Table 20). This same overall pattern appears in the stepwise regression equation for all data combined (Table 21).

pH is not significantly correlated to SPC organisms (Table 18). The overall data set, for the significant multiple regression has a positive coefficient for pH (Tables 20 and 21, respectively), while the remainder of the multiple regressions have non-significant values.

Temperature is significantly correlated to SPC organisms (Table 18), with the signs of the temperature coefficients in the significant stepwise regression equations being significantly positive (Table 21). None of the temperature coefficients in the multiple regression equations are significant (Table 20).

Turbidity appears significant with a positive coefficient in all the multiple regressions for the overall data set, Concord only and C6 (Table 20). It appears as a positive coefficient in the significant stepwise regression equation for all SPC data combined (Table 21), but exhibits no significant correlation for the only data set in which significant stepwise regression could be found (Table 18).

The independent date variables are not correlated to SPC organisms nor appear in any of the significant stepwise regression equations (Tables 18 and 21, respectively), while in only the multiple regression equation for Concord only, SDATE is significant (Table 20).

Membrane - Standard Plate Count--Membrane - Standard Plate Count organisms are correlated with TOC for stations M1 and M8 (Table 18) but the coefficient for TOC has no consistent sign (Table 22). In the significant multiple linear regression equations for m-SPC, TOC is not significant indicating little contribution of the independent variable (Table 23). Total Organic Carbon appears in the stepwise regressions for Concord only, M1 and M8 (Table 21). As in the two way regression equations, there is no consistency in coefficient signs, although TOC appears to be exerting a positive influence on m-SPC at M8.

Two way correlations between m-SPC and free chlorine appear significant at C6 with a positive coefficient for the variable while the significant correlation that appears at M8 for total chlorine has a negative coefficient (Table 18). This same relationship between the two independent chlorine variables is apparent in the multiple regression equations that contain significant chlorine variables (Table 23). The significant stepwise regressions in which chlorine appears, also show free chlorine as having a positive coefficient while that of total chlorine is negative (Table 21). The coefficients for free and total chlorine dominate the equations in which they appear.

TABLE 22. SIGNIFICANT TWO WAY CORRELATIONS AND LINEAR REGRESSION EQUATIONS BETWEEN MICROBIAL PARAMETERS AND TOTAL ORGANIC CARBON (TOC)

Data Set	Dependent Variables	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
M1	LOG[m-SPC] =	5.757 - 0.649 TOC	0.939	0.881	0.0180	5
M8	LOG[m-SPC] =	-1.617 + 0.314 TOC	0.917	0.840	0.0285	5

TABLE 23 . SIGNIFICANT† MULTIPLE LINEAR REGRESSION EQUATIONS BETWEEN LOG[m-SPC] AND PHYSICO-CHEMICAL PARAMETERS FOR FIELD DATA

Data Set	Dependent Variable		Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[m-SPC]	=	$-1.944^{*} + 0.232\ \mathrm{pH}^{*} + 0.059\ \mathrm{TEMP} + 4.977\ \mathrm{CLF}^{*}$ $-5.751\ \mathrm{CLT}^{*} + 0.619\ \mathrm{TURB} + 0.078\ \mathrm{TOC}$ $+0.133\ \mathrm{SDATE} - 0.235\ \mathrm{CDATE}^{*} - 0.009\ \mathrm{ENDOT}$	0.835	0.697	0.0000	62
Manchester Only	LOG[m-SPC]	=	$-2.407 + 0.157\ \mathrm{pH} + 0.106\ \mathrm{TEMP} + 5.209\ \mathrm{CLF}^{*}$ $-5.883\ \mathrm{CLT}^{*} + 0.606\ \mathrm{TURB} + 0.138\ \mathrm{TOC}$ $-0.405\ \mathrm{SDATE} - 0.145\ \mathrm{CDATE} - 0.001\ \mathrm{ENDOT}$	0.814	0.663	0.0000	47
Concord Only	LOG[m-SPC]	=	$0.868 + 0.082\ \mathrm{pH} + 0.038\ \mathrm{TEMP} + 2.019\ \mathrm{CLF}$ $+1.426\ \mathrm{CLT} + 0.277\ \mathrm{TURB} + 0.084\ \mathrm{TOC}$ $+0.488\ \mathrm{SDATE}^{*} + 0.169\ \mathrm{CDATE}^{*}$	0.739	0.546	0.0000	50
M3, M4	LOG[m-SPC]	=	$-8.419 + 1.158\ \mathrm{pH} + 0.132\ \mathrm{TEMP} + 7.303\ \mathrm{CLF}^{*}$ $-7.760\ \mathrm{CLT}^{*} + 0.325\ \mathrm{TURB} + 0.087\ \mathrm{TOC}$ $-0.680\ \mathrm{SDATE} - 0.179\ \mathrm{CDATE} + 0.031\ \mathrm{ENDOT}$	0.823	0.678	0.0005	33
M3	LOG[m-SPC]	=	$-7.334 + 1.062\ \mathrm{pH} + 0.118\ \mathrm{TEMP} + 9.914\ \mathrm{CLF}^{*}$ $-10.425\ \mathrm{CLT}^{*} + 2.086\ \mathrm{TURB} - 0.022\ \mathrm{TOC}$ $-1.029\ \mathrm{SDATE} - 0.078\ \mathrm{CDATE}$	0.879	0.773	0.0180	19

†0.05 level, multiple correlation coefficient $\geq$ 0.700
*significant variables at the 0.05 level

The unique chlorine trends found for m-SPC and the other microbial variables are further treated under Hypothesis 6.

pH does not appear significantly correlated to m-SPC (Table 18) and appears in the significant multiple regressions and one stepwise regression for the overall data set with a positive coefficient (Tables 23 and 21, respectively).

Temperature is significantly correlated to m-SPC at station C2 (Table 18). For the multiple regressions temperature exhibits no significant coefficients (Table 23). A very small positive coefficient was found for the data sets C5-C8, M3, M4 and M1 for the significant stepwise regressions (Table 21). The independent variable turbidity appeared as a positive coefficient in the stepwise regression for Manchester and Concord combined but not significantly in the multiple regressions (Tables 21 and 23, respectively).

There is no consistency in the appearance of SDATE and CDATE in both the significant multiple and stepwise regression equations (Tables 23 and 21, respectively), although SDATE is correlated to m-SPC at C2 (Table 18).

Acid-fast--Only the multiple regression equations for stations M2 and M3 were significant for acid-fast organisms (Table 24). The total chlorine coefficient at M3 exhibit the same pattern as it does for the SPC and m-SPC organisms.

One significant stepwise regression was found for acid-fast organisms. This was for the C4 data set (Table 21). No significant correlations for acid-fast organisms and any physico-chemical parameters were found. (Table 18)

Total coliforms--Total coliforms were significantly negatively correlated with TOC for M4 (Table 18). Total Organic Carbon is the only independent variable appearing in the M4 data set for significant stepwise regressions and it appears with a negative coefficient (Table 21), but for only three data points.

Total coliforms are also negatively correlated to CDATE for M5-M8 and CDATE appears as the only variable in the significant stepwise regression for that data set (Tables 18 and 21, respectively). CDATE, also, appears with a negative coefficient for the C4 significant stepwise regression equation for total coliforms.

One multiple linear regression equation was significant for total coliforms. This was for all Manchester (Table 25). As for the other microbial dependent variables the independent chlorine variables show a positive effect for free chlorine and a negative effect for total chlorine with the chlorine variables dominating the equation. pH, also, appears significant in the multiple regression with a positive coefficient.

TABLE 24. SIGNIFICANT† MULTIPLE LINEAR REGRESSION EQUATIONS BETWEEN LOG[ACID-FAST] AND PHYSICO-CHEMICAL PARAMETERS FOR FIELD DATA

Data Set	Dependent Variable		Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
M2	LOG[AF]	=	-1.764 + 0.398 pH - 0.118 TEMP* - 1.123 CLF -0.059 CLT + 0.633 TURB + 0.043 TOC +1.391 SDATE* - 0.228 CDATE	0.787	0.619	0.0149	26
M3	LOG[AF]	=	0.852 - 0.448 pH + 0.055 TEMP + 3.635 CLF -1.778 CLT* - 1.226 TURB* + 0.051 TOC -0.278 SDATE - 0.088 CDATE + 0.368 ENDOT	0.999	0.999	0.0381	11

---

†0.05 level, multiple correlation coefficient $\geq$ 0.700

*significant variable at the 0.05 level

TABLE 25. SIGNIFICANT† MULTIPLE LINEAR REGRESSION EQUATIONS BETWEEN LOG[TOTAL COLIFORMS] AND PHYSICO-CHEMICAL PARAMETERS FOR FIELD DATA

Data Set	Dependent Variable		Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
Manchester Only	LOG[TCOLI]	=	-10.085* + 1.719 pH* - 0.014 TEMP + 13.760 CLF* -12.989 CLT* - 0.493 TURB + 0.094 TOC + 0.179 SDATE - 0.182 CDATE - 0.052 ENDOT	0.941	0.886	0.0012	37

---

†0.05 level, multiple correlation coefficient $\geq$ 0.700

*significant variable at the 0.05 level

Endotoxins--Endotoxin as a dependent variable appeared significant in only the stepwise regression equation for the C8 data set (Table 21). Here it appears to be highly influenced by turbidity.

In summary it appears that TOC does not appear to be important in governing microbial concentrations in the water treatment and distribution systems examined, while increasing values of pH, temperature, and turbidity are correlated with increasing concentrations of both SPC and m-SPC organisms.

Hypothesis 5. The change in bacterial quality between two neighboring locations is dependent on the physico-chemical characteristics existing between them--

A stepwise multiple regression of the differences between logs of microbial numbers at two successive stations was performed:

$$\mathrm{LOG}[N(i)] - \mathrm{LOG}[N(i-1)] = f\ (\text{physico-chemical variables})$$

where N is the microbial parameter and i equals the site studied. The regression was performed using physico-chemical variables at i-1 and then with those at i (Table 26).

The regression indicates that the changes in only m-SPC and acid-fast organisms are significantly influenced by the associated physico-chemical parameters and only at certain sites.

All the significant regressions for m-SPC occur within the Manchester water treatment plant. For the change in logs between M3-M2, pH appears with a negative coefficient. The significant regression equation for M4-M3 has a negative coefficient for free chlorine with a higher positive coefficient for total chlorine. This indicates that the growth recorded between M3-M4 could be promoted by both free available chlorine and combined chlorine. Free chlorine has a very high positive coefficient in the regression equation for M5-M4, indicating a negative correlation with inactivation. This should be tempered with caution as there are only three data points.

The physico-chemical characteristics appear to significantly influence acid-fast organisms in the Manchester distribution system only. Total endotoxin effects acid-fast for both M6-M5 and M7-M6. For the M6-M5 data set total endotoxin has a negative coefficient in the equation using the physico-chemical variables from M5 indicating total endotoxin correlated with inactivation, while the coefficient is positive for the equation based on M6 (M7-M6 data set) indicating a negative correlation with inactivation.

The equation for M6-M5 based on M6's physico-chemical variables indicates TOC correlated with inactivation.

The equations for the C5-C4 data set, based on either C4 or C5, indicate that both temperature and turbidity correlated with inactivation during disinfection.

TABLE 26. SIGNIFICANT STEPWISE MULTIPLE LINEAR REGRESSION RESULTS OF DIFFERENCES BETWEEN LOGS OF MICROBIAL NUMBERS AT TWO SUCCESSIVE STATIONS: (i.e. LOG[N(i)] - LOG[N(i-1)] = f(physio-chemical variables)†

Data Set	Dependent Variables	Linear Regression Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
M3-M2	LOG[m-SPC(2)] - LOG[m-SPC(1)]	= 9.081 - 1.621 pH(1)	0.999	0.999	0.0124	3
M4-M3	LOG[m-SPC(2)] - LOG[m-SPC(1)]	= - 0.239 - 7.119 CLF(1) + 8.220 CLT(1)	0.859	0.739	0.0002	16
M5-M4	LOG[m-SPC(2)] - LOG[m-SPC(1)]	= -10.935 + 15.469 CLF(2)	0.998	0.996	0.0408	3
M6-M5	LOG[AF(2)] - LOG[AF(1)]	= 0.715 - 0.211 ENDOT(1)	0.736	0.541	0.0374	8
	LOG[AF(2)] - LOG[AF(1)]	= 1.148 - 0.297 TOC(2)	0.702	0.493	0.0078	13
M7-M6	LOG[AF(2)] - LOG[AF(1)]	= -1.689 + 0.269 ENDOT(1)	0.813	0.661	0.0491	6
C5-C4	LOG(AF(2)] - LOG[AF(1)]	= 1.638 - 0.062 TEMP(1) - 1.369 TURB(1)	0.753	0.567	0.0012	19
	LOG[AF(2)] - LOG[AF(1)]	= 1.597 - 0.080 TEMP(2) - 0.829 TURB(2)	0.764	0.583	0.0009	19

---

*0.05 level, multiple correlation coefficient ≥0.700

†possible variables for regression: pH, CLF, CLT, TEMP, TOC, ENDOT, TURB

Growth of m-SPC across the GAC filter appears to be positively correlated to free chlorine and negatively correlated for total chlorine. Neither for SPC and total coliform does there appear to be a relationship between neighboring locations for pH, temperature, free chlorine, total chlorine, turbidity and TOC.

Hypothesis 6. Chlorine residuals are inversely related to microbial concentrations--

Previous studies have suggested that chlorine residuals are inversely related to microbial concentrations (Snead _et al._, 1980). Looking at the relationship between SPC and m-SPC organisms versus station for Concord and Manchester (Figures 18 and 19) it appears that in conjunction with chlorine being added between M4 - M5 and C4 - C5 a sharp drop in organisms occurs. Prechlorination at M2 and the increase of organisms within each distribution system as the residual decreases also indicate this inverse relationship. However, examination of the two-way correlations and regression equations of SPC and m-SPC against free and total chlorine show no significant relationship employing the aforementioned criteria between SPC and total and free chlorine, while two equations were significant for m-SPC (Tables 18, 27, 28, 29 and 30). The significant regression equations indicate an inverse effect for total chlorine and a positive effect for free chlorine. In other words, total chlorine appears to decrease m-SPC counts, while free chlorine appears to increase such counts.

The significant multiple linear regression equations for SPC and m-SPC (Tables 20 and 23) also indicate this trend but more important is the comparison between the coefficients for the total and free chlorine variables. For eleven out of the twelve significant equations the magnitude of the negative coefficient for total chlorine is higher than the positive free chlorine coefficient. This strongly indicates that both free and combined chlorine are bactericidal in the system, however combined chlorine residuals would appear to be more effective at reducing microbial levels.

This trend continues for the stepwise multiple linear regressions for both the microbial parameters (Table 21) and the differences between logs of microbial numbers at two successive stations (Table 26), with two notable exceptions. In the stepwise regression for m-SPC for station C6 the coefficient indicate that m-SPC organisms increase with the increase in free chlorine. The difference of the logs for m-SPC between M5 and M4 also shows the growth of m-SPC organism with increasing chlorine, however this equation is based on three data points and is thus somewhat questionable.

Examination of the data collected in this study does not consistently support the hypothesis that chlorine residuals are inverselv related to microbial concentrations in distribution systems. In fact several significant correlations appear to indicate that increasing levels of chlorine in distribution systems may lead to increasing microbial concentrations.

Hypothesis 7. Microbial quality is altered upon passage through the GAC bed--

One of the primary objectives of this study was to determine whether microbial regrowth occurs across the carbon bed at Manchester. For SPC, m-SPC, acid-fast organisms and total endotoxins, paired t-tests were conducted

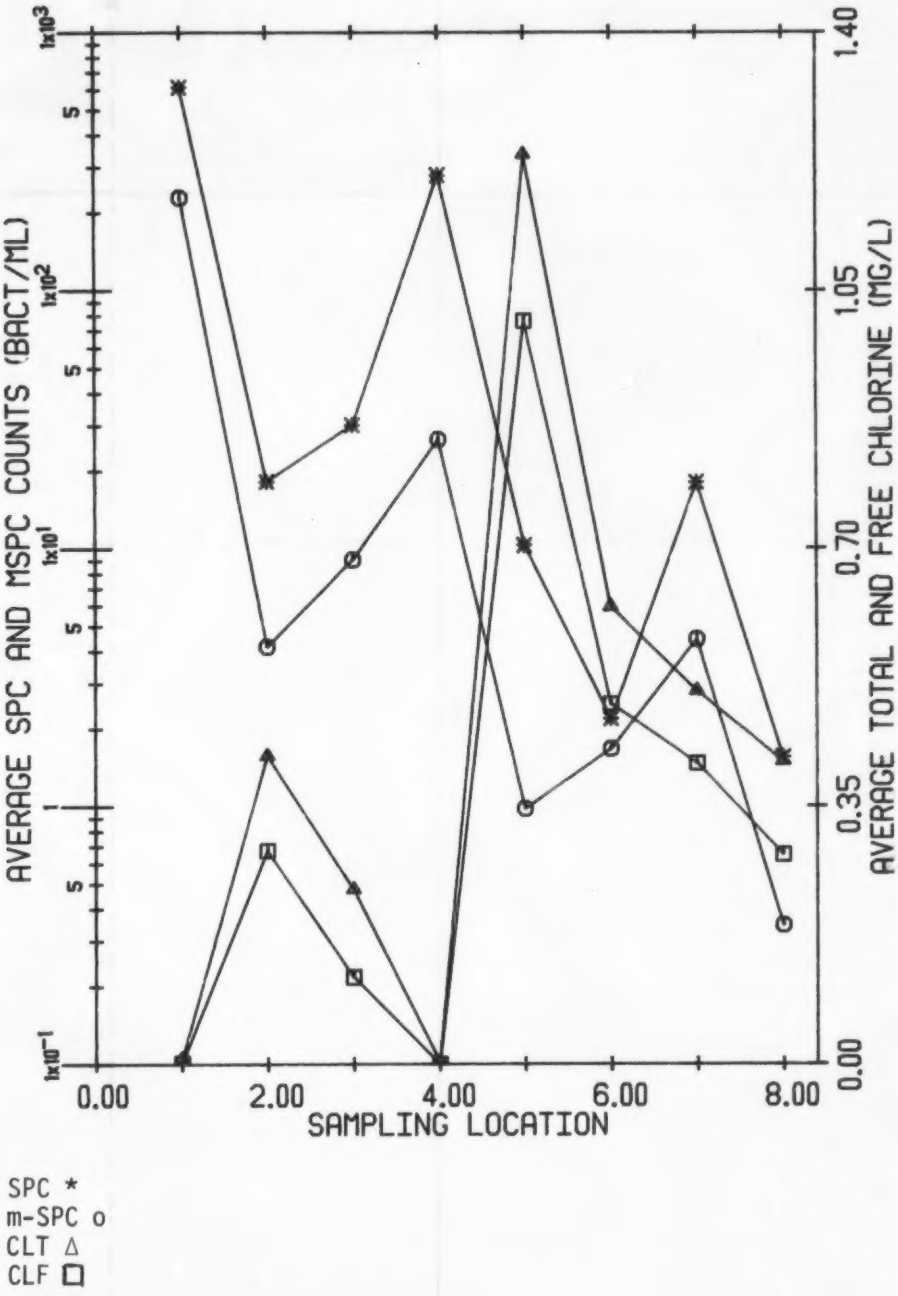
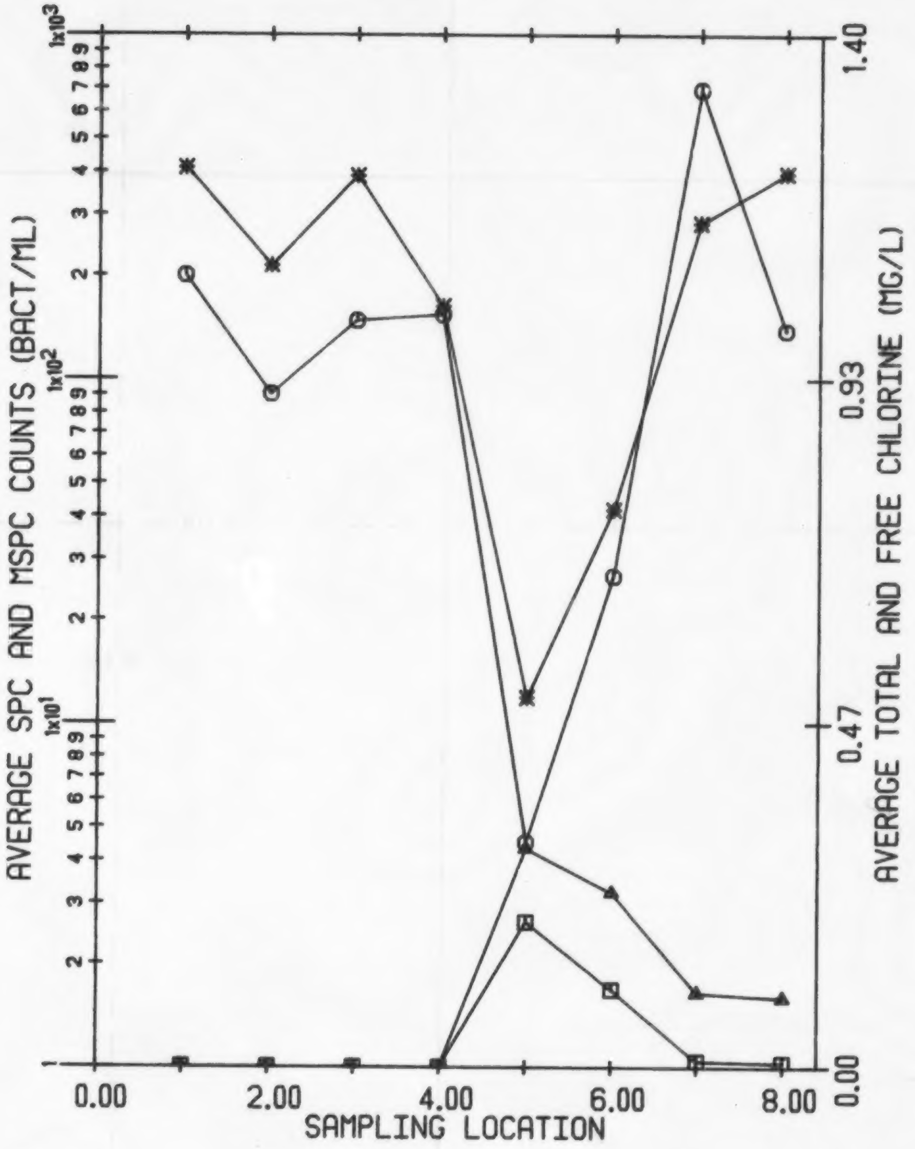


Figure 18. Means of SPC, m-SPC, total chlorine and free chlorine vs. station for Manchester.



SPC *
m-SPC o
CLT Δ
CLF □

Figure 19. Means of SPC, m-SPC, total chlorine and free chlorine vs. station for Concord.

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TABLE 27. TWO-WAY CORRELATIONS AND LINEAR REGRESSION EQUATIONS BETWEEN LOG[SPC] AND FREE CHLORINE (CLF)

Data Set	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[SPC] = 1.608 - 1.918 CLF	0.521	0.271	0.0000	462
Manchester Only	LOG[SPC] = 1.117 - 1.210 CLF	0.418	0.179	0.0000	217
Concord Only	LOG[SPC] = 1.953 - 4.220 CLF	0.462	0.214	0.0000	245
M5 - M8	LOG[SPC] = 0.275 - 0.117 CLF	0.073	0.005	0.4760	98
C5 - C8	LOG[SPC] = 1.514 - 2.206 CLF	0.309	0.096	0.0006	119
M1, C1	LOG[SPC] = 2.351 - 11.039 CLF	0.107	0.012	0.4025	63
M1	LOG[SPC] = 2.303 - 10.079 CLF	0.116	0.014	0.5329	31
M2	LOG[SPC] = 0.699 - 0.107 CLF	0.033	0.001	0.8611	30
M3	LOG[SPC] = 0.731 - 1.699 CLF	0.359	0.129	0.0657	27
M4	†				
M5	LOG[SPC] = 0.456 - 0.182 CLF	0.102	0.010	0.6357	24
M6	LOG[SPC] = 0.452 - 0.839 CLF	0.307	0.094	0.1648	22
M7	LOG[SPC] = 1.003 - 1.636 CLF	0.412	0.169	0.0263	29
M8	LOG[SPC] = 0.164 - 0.159 CLF	0.054	0.003	0.8084	23
C1	†				
C2	†				
C3	†				
C4	†				
C5	LOG[SPC] = 1.042 - 1.181 CLF	0.229	0.053	0.2142	31
C6	LOG[SPC] = 1.038 + 1.952 CLF	0.348	0.121	0.0512	32
C7	LOG[SPC] = 1.854 + 2.078 CLF	0.097	0.009	0.6101	30
C8	LOG[SPC] = 1.439 - 0.643 CLF	0.021	0.000	0.9186	26

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†-variance-covariance matrix singular

TABLE 28. TWO-WAY CORRELATIONS AND LINEAR REGRESSION EQUATIONS BETWEEN LOG[m-SPC] AND TOTAL CHLORINE (CLT)

Data Set	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[m-SPC] = 1.310 - 1.983 CLT	0.550	0.303	0.0000	136
Manchester Only	LOG[m-SPC] = 0.728 - 1.242 CLT	0.447	0.200	0.0000	83
Concord Only	LOG[m-SPC] = 1.978 - 3.361 CLT	0.575	0.331	0.0000	53
M5 - M8	LOG[m-SPC] = -0.280 + 0.008 CLT	0.003	0.000	0.9881	25
C5 - C8	LOG[m-SPC] = 2.119 - 3.862 CLT	0.573	0.328	0.0022	26
M1, C1	†				
M3, M4	LOG[m-SPC] = 0.772 - 2.433 CLT	0.484	0.234	0.0009	44
M1	†				
M2	LOG[m-SPC] = 0.056 + 0.584 CLT	0.312	0.097	0.4131	9
M3	LOG[m-SPC] = 0.605 - 2.121 CLT	0.481	0.231	0.0370	9
M4	LOG[m-SPC] = 0.791 + 9.962 CLT	0.244	0.059	0.2407	25
M5	LOG[m-SPC] = -1.733 - 1.291 CLT	0.516	0.267	0.2355	7
M6	LOG[m-SPC] = -0.653 + 0.312 CLT	0.099	0.010	0.8138	8
M7	LOG[m-SPC] = 1.685 - 1.929 CLT	0.744	0.553	0.1496	5
M8	LOG[m-SPC] = 0.980 - 3.469 CLT	0.879	0.773	0.0496*	5
C1	†				
C2	†				
C3	†				
C4	†				
C5	LOG[m-SPC] = -0.161 + 2.079 CLT	0.514	0.264	0.2378	7
C6	LOG[m-SPC] = -0.502 + 7.058 CLT	0.645	0.416	0.0841	8
C7	LOG[m-SPC] = 2.915 - 3.753 CLT	0.566	0.321	0.2413	6
C8	LOG[m-SPC] = 1.541 + 13.779 CLT	0.549	0.301	0.3382	5

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†-variance-covariance matrix singular

*-significant at 0.05 level

TABLE 29. TWO-WAY CORRELATIONS AND LINEAR REGRESSION EQUATIONS BETWEEN LOG[m-SPC] AND FREE CHLORINE (CLF)

Data Set	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[m-SPC] = 1.169 - 1.897 CLF	0.476	0.227	0.0000	136
Manchester Only	LOG[m-SPC] = 0.598 - 1.094 CLF	0.364	0.132	0.0007	83
Concord Only	LOG[m-SPC] = 1.856 - 4.014 CLF	0.505	0.255	0.0001	53
M5 - M8	LOG[m-SPC] = -0.357 + 0.139 CLF	0.061	0.004	0.7722	25
C5 - C8	LOG[m-SPC] = 1.732 - 3.516 CLF	0.473	0.224	0.0147	26
M3, M4	LOG[m-SPC] = 0.631 - 2.189 CLF	0.345	0.118	0.0219	44
C1, M1	†				
M1	†				
M2	LOG[m-SPC] = -0.006 + 1.059 CLF	0.494	0.244	0.1770	9
M3	LOG[m-SPC] = 0.262 - 1.388 CLF	0.292	0.085	0.2257	19
M4	†				
M5	LOG[m-SPC] = -1.609 + 1.258 CLF	0.617	0.380	0.1403	7
M6	LOG[m-SPC] = -0.434 - 0.045 CLF	0.016	0.000	0.9705	8
M7	LOG[m-SPC] = 2.283 - 3.448 CLF	0.774	0.599	0.1245	5
M8	LOG[m-SPC] = 0.592 - 3.622 CLF	0.813	0.661	0.0943	5
C1	†				
C2	†				
C3	†				
C4	†				
C5	LOG[m-SPC] = 0.328 + 0.911 CLF	0.288	0.083	0.5307	7
C6	LOG[m-SPC] = 0.704 + 4.094 CLF	0.731	0.535	0.0393*	8
C7	†				
C8	†				

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† variance-covariance matrix singular

* significant at 0.05 level

TABLE 30. TWO-WAY CORRELATIONS AND LINEAR REGRESSION EQUATIONS BETWEEN LOG[SPC] AND TOTAL CHLORINE (CLT)

Data Set	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[SPC] = 1.717 - 1.783 CLT	0.581	0.338	0.0000	463
Manchester Only	LOG[SPC] = 1.210 - 1.138 CLT	0.465	0.216	0.0000	217
Concord Only	LOG[SPC] = 2.146 - 4.054 CLT	0.642	0.412	0.0000	246
M5 - M8	LOG[SPC] = 0.279 - 0.099 CLT	0.070	0.005	0.4914	98
C5 - C8	LOG[SPC] = 1.904 - 3.106 CLT	0.471	0.222	0.0000	120
M1, C1	LOG[SPC] = 2.351 - 2.399 CLT	0.107	0.011	0.4025	63
M1	LOG[SPC] = 2.303 - 2.191 CLT	0.116	0.014	0.5329	31
M2	LOG[SPC] = 0.855 - 0.452 CLT	0.152	0.023	0.4224	30
M3	LOG[SPC] = 1.071 - 2.304 CLT	0.542	0.295	0.0034	27
M4	LOG[SPC] = 1.229 + 8.707 CLT	0.152	0.023	0.4138	31
M5	LOG[SPC] = 0.576 - 0.242 CLT	0.154	0.024	0.4734	24
M6	LOG[SPC] = 0.628 - 0.959 CLT	0.334	0.111	0.1289	22
M7	LOG[SPC] = 1.025 - 1.359 CLT	0.361	0.130	0.0545	29
M8	LOG[SPC] = 0.066 + 0.144 CLT	0.051	0.003	0.8177	23
C1	†				
C2	†				
C3	†				
C4	†				
C5	LOG[SPC] = 1.108 - 1.004 CLT	0.189	0.036	0.3086	31
C6	LOG[SPC] = 1.233 + 0.045 CLT	0.005	0.000	0.9773	32
C7	LOG[SPC] = 2.175 - 3.109 CLT	0.281	0.079	0.1324	30
C8	LOG[SPC] = 1.811 - 4.208 CLT	0.379	0.144	0.0511	27

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†-variance-covariance matrix singular

(Table 11). There is a statistically significant difference between the densities at M3 and M4 for both SPC and m-SPC organisms, with carbon effluents containing an average of 0.649 and 0.743 logs more microorganisms, respectively. In the case of acid-fast and total endotoxins, there is no statistically significant difference between influent and effluent concentrations.

Hypothesis 8. Endotoxin levels provide a good estimate of indicator organisms in raw, partially treated and finished water--

The examination of the correlation coefficients for total endotoxin and the bacterial parameters (Table 18) show no significant correlation using these statistical tests.

In the stepwise multiple linear regression results of bacterial parameters versus physical parameters (Table 21), the variable total endotoxin appears in three regression equations. It appears in the SPC equation for all data pooled, m-SPC for pooled Concord data and total coliform for C4, in all cases with a very low coefficient.

Total endotoxin contributes very little in the significant multiple linear regression equations for SPC and m-SPC (Tables 20 and 23) but appears to be significant for acid-fast in the stepwise multiple linear regression analysis of the differences between logs of microbial numbers at two successive stations (Table 26), however even in these regressions, the coefficient of the endotoxin concentration has no consistent sign. While the correlation between endotoxins and various indicator organism are statistically different than zero their absolute values are relatively low. Thus from a practical point of view the utility of the LAL endotoxin assay as a surrogate for indicator organisms is minimal.

Hypothesis 9. m-SPC is a good estimator of SPC in raw, partially treated and finished water--

Taylor and Geldreich (1979) have reported on an alternative, membrane filter, modification of the standard plate count used in water microbiology (APHA, et al., 1980). While data were presented illustrating the comparability of the two techniques, the samples were limited to those within water distribution systems and swimming pools and sampling was limited to several months.

During the course of this study a total of 160 parallel samples for m-SPC/SPC was taken from the Manchester and Concord treatment plants and distribution systems. The total number of samples for which data were collected was 129.

The mean values for SPC and m-SPC through the two systems are listed in Table 7 and 8 and are graphically represented in Figure 18. Standard Plate Count and m-SPC trends appear to parallel each other with SPC counts tending to be slightly higher. Of noticeable exception is at stations M7 and C7. Both these stations occur at sampling ports within fire stations.

Figure 20 is the scatter plot of log[SPC] versus log[m-SPC] for the entire data set. From a correlation analysis, the following best fit

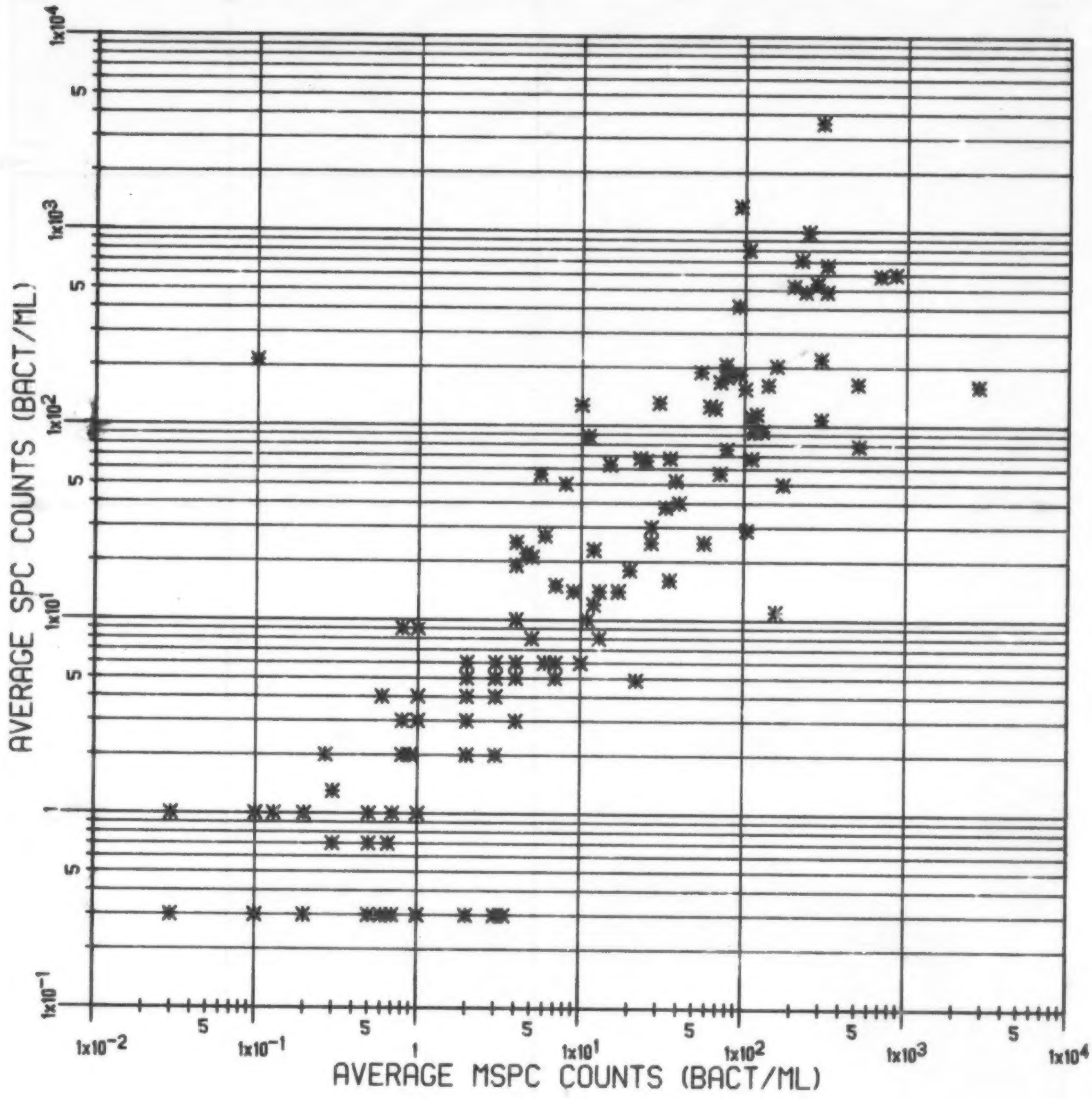

Figure 20. SPC vs. m-SPC for Manchester and Concord combined.

equation was calculated:

$$\mathrm{Log[SPC]} = 0.43358 + 0.78930\ \mathrm{Log[m\text{-}SPC]}$$

with a correlation coefficient of 0.853 (Table 31). At low microorganism concentrations the above equation indicates that the m-SPC procedures leads to lower counts than the SPC procedure, however above approximately 100 organisms per ml the opposite is true. t-tests performed on the slope and the least squares constant (Table 31) indicate that the slope is significantly different than one and the constant is significantly different than zero. After performing the analysis for Manchester and Concord combined the data were assessed by plant alone, distribution system, raw water, each station individually and M3, M4 combined. M3 and M4 were examined together as approximately one-third of the total data set from these stations. The best fit equations for each plant (Table 31, Figures 21 and 22) are:

$$\mathrm{Log[SPC]}_{\mathrm{man.}} = 0.42507 + 0.77904\ \mathrm{Log[m\text{-}SPC]}$$

$$\mathrm{Log[SPC]}_{\mathrm{con.}} = 0.47700 + 0.77414\ \mathrm{Log[m\text{-}SPC]}$$

which approximates that for both systems combined. The remainder of the equations vary from this pattern and it appears as the number of points in the data set becomes fewer, the equations are no longer significant.

The equation for M3, M4 combined exhibits a high coefficient with a slope approaching one, which is also indicated in the equation for M3 and M4 alone (Figure 23, Table 32). For virtually all subsets of the data examined there was a high statistically significant correlation between SPC and m-SPC values. In many cases however there is a numerical difference between the values of these parameters recorded at a given station or time. This suggests that while the m-SPC procedure is a useful substitute for the SPC procedure the numerical relationship between these two parameters is not a universal one. Never-the-less the m-SPC procedure is a useful one in a given location provided that a site specific standard curve is established, in much the same way that TOC is used as an indicator for Biochemical Oxygen Demand (BOD) in wastewater treatment.

ANALYSIS OF PILOT UNIT DATA

Scope of Analysis

The following sections are the results and discussion of the physico-chemical and microbial trends for the pilot unit.

Physico-Chemical and Biological Correlations for the Pilot Unit

Each experiment's data were analyzed for two-way correlation coefficients in the following manner: all data combined, the influent and control column

TABLE 31. TWO-WAY CORRELATIONS AND LINEAR REGRESSION EQUATIONS BETWEEN LOG[SPC] AND LOG[m-SPC]

Data Set	Equation	Multiple Correlation Coefficient	ρ^2	Significance	N
All	LOG[SPC] = 0.434 + 0.789 LOG[m-SPC]	0.854	0.729	0.0000	129
Manchester Only	LOG[SPC] = 0.425 + 0.779 LOG[m-SPC]	0.802	0.643	0.0000	76
Concord Only	LOG[SPC] = 0.477 + 0.774 LOG[m-SPC]	0.789	0.623	0.0000	53
M5 - M8	NS				20
C5 - C8	LOG[SPC] = 0.388 + 0.728 LOG[m-SPC]	0.842	0.708	0.0000	26
M1, C1	LOG[SPC] = 0.729 + 0.829 LOG[m-SPC]	0.873	0.762	0.0005	11
M3, M4	LOG[SPC] = 0.322 + 0.908 LOG[m-SPC]	0.864	0.746	0.0000	42
M1	LOG[SPC] = 0.462 + 0.885 LOG[m-SPC]	0.967	0.934	0.0073	5
M2	LOG[SPC] = 0.105 + 1.167 LOG[m-SPC]	0.778	0.605	0.0135	9
M3	LOG[SPC] = 0.393 + 0.877 LOG[m-SPC]	0.865	0.748	0.0000	16
M4	LOG[SPC] = 0.220 + 0.983 LOG[m-SPC]	0.849	0.722	0.0000	26
M5	NS				6
M6	LOG[SPC] = 0.440 + 0.538 LOG[m-SPC]	0.757	0.572	0.0490	7
M7	NS				5
M8	*				
C1	NS				6
C2	NS				8
C3	NS				6
C4	NS				7
C5	NS				7
C6	LOG[SPC] = 0.207 + 0.832 LOG[m-SPC]	0.942	0.887	0.0005	8
C7	NS				6
C8	NS				5

NS-not significant
*-only 2 pts.

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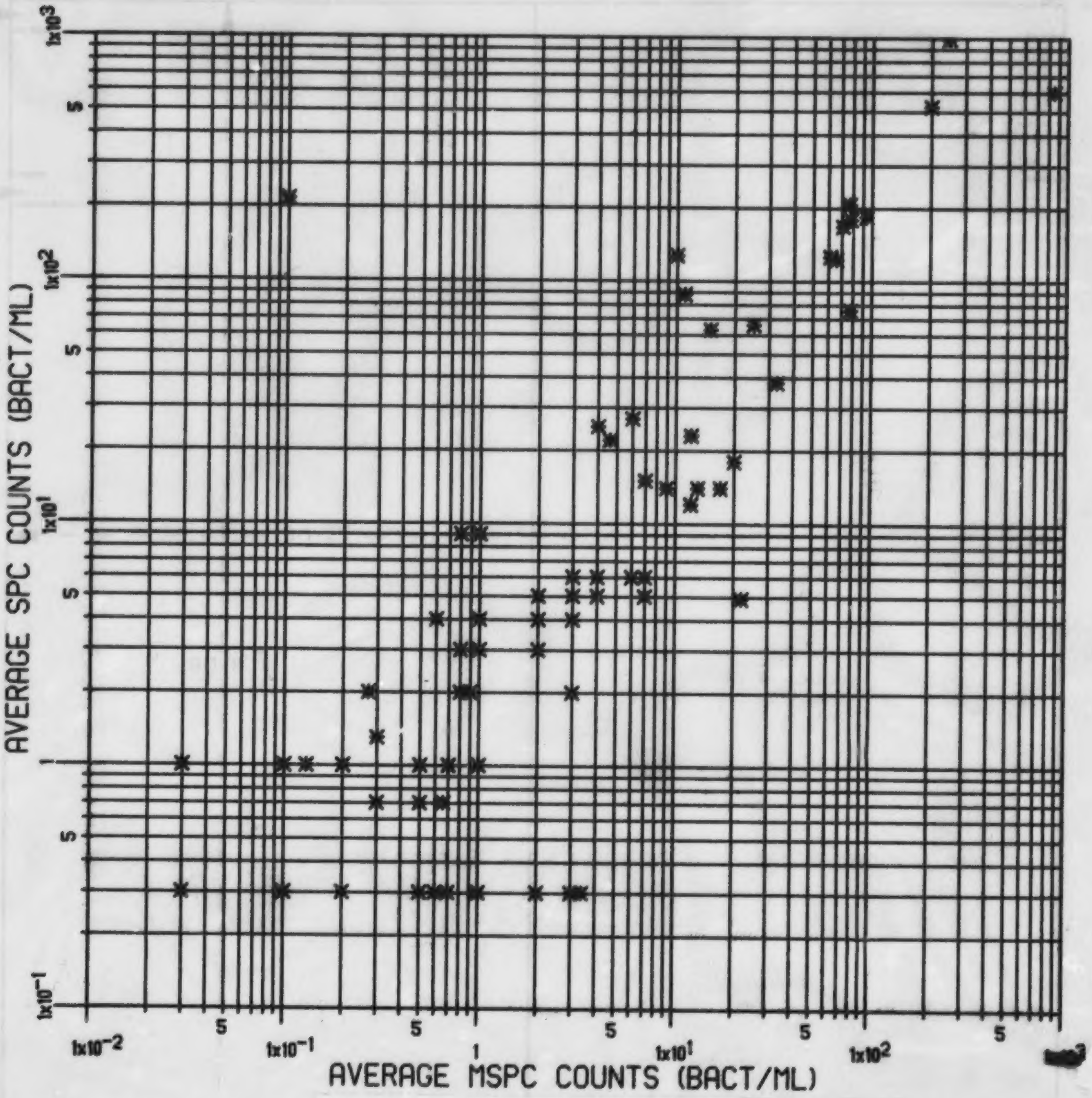

Figure 21. SPC vs. m-SPC for Manchester.

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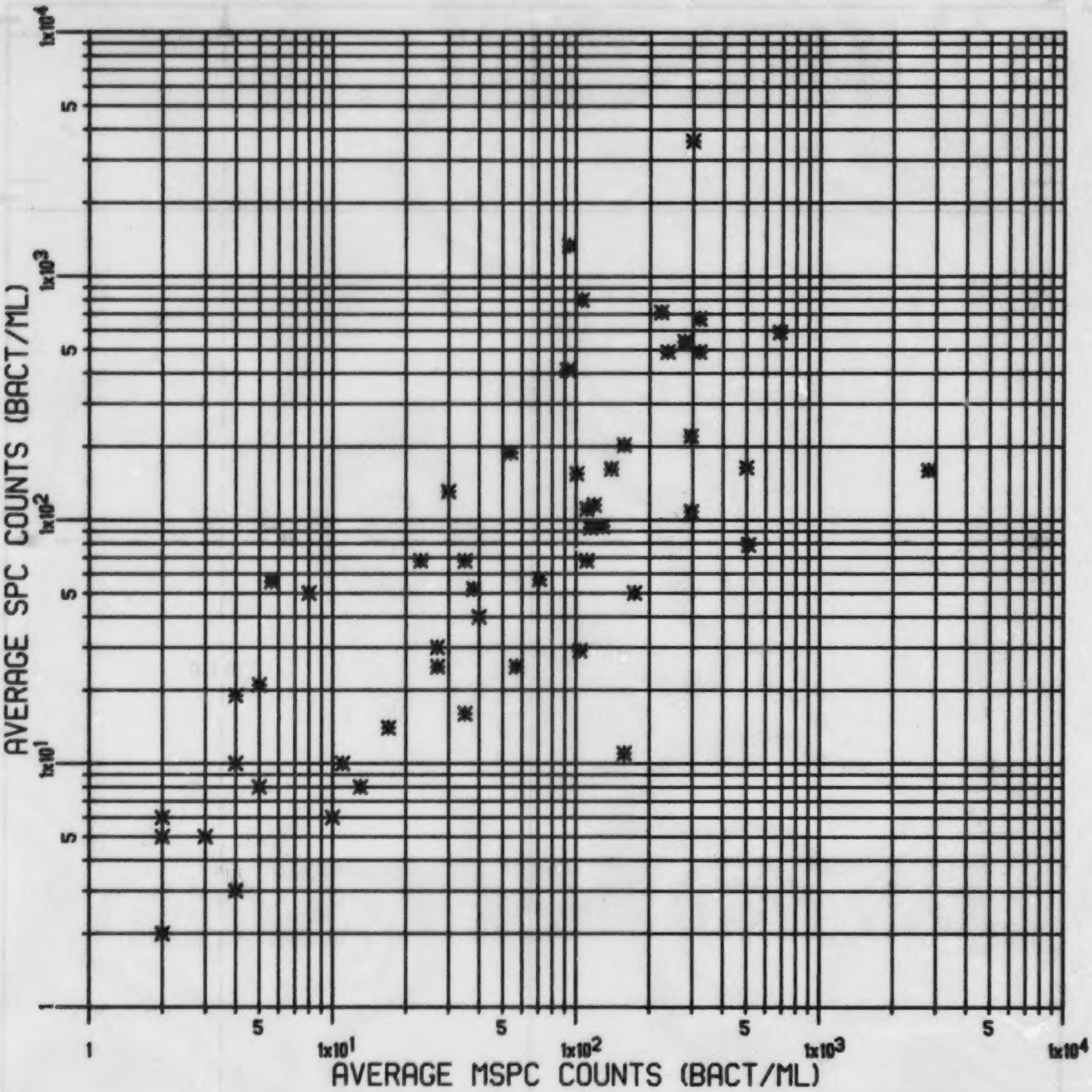

Figure 22. SPC vs. m-SPC for Concord.

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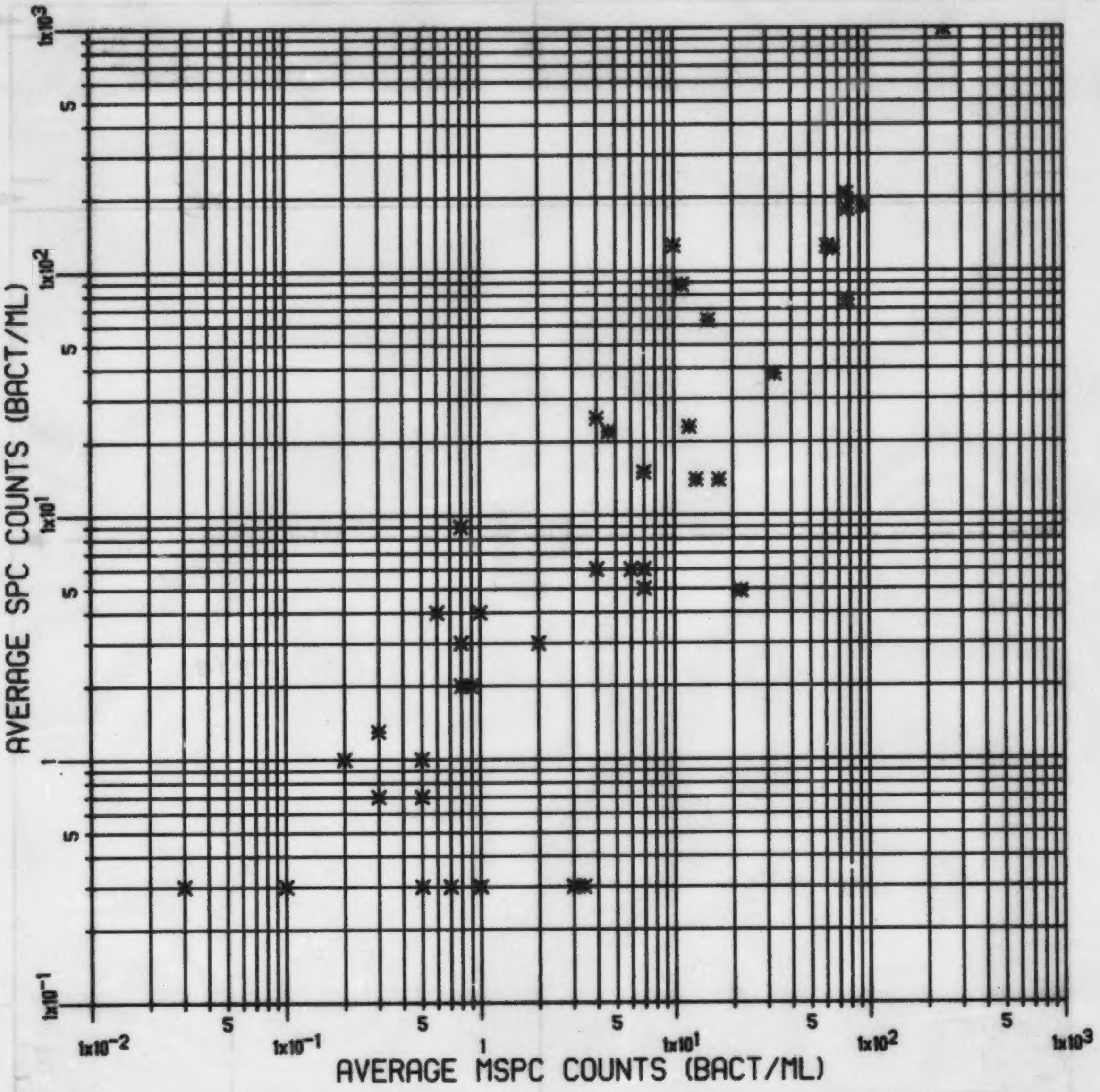

Figure 23. SPC vs. m-SPC for stations M3 and M4.

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TABLE 32. t-TEST TO DETERMINE THE CLOSENESS OF THE LEAST SQUARES CONSTANT TO ZERO AND SLOPE TO ONE BETWEEN LOG[SPC] AND LOG[m-SPC]

Data Set	N	t-Test (constant)	Value	Significance[†]	t-Test (slope)	Value	Significance
All*	129	7.086	0.434	0.0000	4.738	0.789	b
Concord only*	53	3.072	0.477	0.0034	2.680	0.774	b
Manchester only*	76	5.968	0.425	0.0000	3.270	0.779	b
C5 - C8*	26	2.443	0.388	0.0223	-2.854	0.728	b
M5 - M8	20	2.595	0.412	0.0183	-3.575	0.329	b
M1, C1*	11	2.324	0.729	0.0452	1.100	0.829	c
M3, M4*	42	3.599	0.322	0.0000	1.090	0.908	c
M1*	5	1.729	0.462	0.1823	0.846	0.885	c
M2*	9	0.521	0.105	0.6186	0.468	1.167	c
M3*	16	3.039	0.393	0.0088	0.906	0.877	c
M4*	26	1.557	0.220	0.1325	0.1394	0.983	c
M5	6	0.933	0.507	0.4038	1.590	0.019	c
M6*	7	2.225	0.440	0.0767	2.224	0.538	b
M7	5	-0.687	-0.223	0.5413	0.371	1.173	c
M8	N=2						
C1	6	2.163	1.344	0.0965	1.369	0.591	b
C2	8	1.476	0.940	0.1995	-1.466	0.487	c
C3	6	1.639	1.101	0.1764	1.382	0.563	c
C4	7	1.376	1.119	0.2272	1.332	0.457	c
C5	7	1.103	0.411	0.3204	0.980	0.710	c
C6*	8	1.421	0.207	0.2050	-1.370	0.832	c
C7	6	1.203	0.806	0.2953	2.077	0.464	b
C8	5	0.011	0.008	0.9921	0.439	1.178	c

[†] significance < 0.05 indicates constant significant from zero
b=slope significant from 1.0 at 0.05 level
c=slope not significant from 1.0 at 0.05 level
*significant regression equation

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combined, all GAC columns combined, and each column and influent separate. The other two data sets consisted of all influent data combined (Table 33) as well as station T3 combined (Table 34) for all three experiments and were sampled as all the data combined, experiment 1 and 2 combined, experiment 1 and 3 combined, and experiment 2 and 3 combined. All possible two-way correlations were considered.

All three experiments produced numerous significant two-way correlation coefficients, however, experiment 3 (Table 35) produced twice as many significant correlations as either of the first two experiments. Even with the large number of significant correlations there were very few pairs of parameters with significant correlation coefficients in all three experiments. Furthermore, by eliminating all of the physico-chemical versus physio-chemical correlations the only pair of parameters from the data samples that did significantly and consistently correlate were total endotoxins versus free endotoxins.

Another correlation that appeared prominently, but only in experiments 2 (Table 36) and 3 was dissolved oxygen versus free endotoxin. This correlation occurred in almost every type of data sample for both experiments. Also, experiment 1 (Table 37) and the influent combined data set had many significant correlations for acid-fast versus time. The station T3 combined data set produced positive significant correlations for dissolved oxygen versus m-SPC, SPC versus m-SPC, and a negative correlation for temperature versus m-SPC.

There were many other significant correlations, yet they did not occur with enough frequency in any of the data sets for them to be considered consequential.

Anovas

Two-way anovas (time x station) were performed on all three experiments as well as with data combinations consisting of all of the influent and all of station T3 values to test for the dependency of the parameters on time and station (Table 38). For experiments 1 and 3, SPC and m-SPC levels were signifcantly different for both time and station (Figures 24,25,26, and 27). However, experiment 2 displayed a significant difference with time and not station for SPC while m-SPC values for this same experiment showed a significant difference in station, but not in time (Figures 28, 29).

Free endotoxin for experiment 1 and total endotoxin for both experiments 1 and 2 were not significantly different at different stations, but were significantly different with time (Figures 30, 31, 32, 33). Experiment 2 and 3 had both significant differences with time and station for free endotoxin while the same was true in experiment 3 (Figures 34, 35) for total endotoxin.

Acid-fast bacteria were not influenced by time or station for experiments 2 and 3 (Figures 36, 37), but were significantly affected by time, but not by station for experiment 1 (Figure 38).

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TABLE 33. SIGNIFICANT TWO-WAY CORRELATION COEFFICIENTS FOR THE COMBINED INFLUENT DATA FROM ALL THREE EXPERIMENTS

Data Set	Variables	Correlation Coefficient	Significance	N
ALL	Temp-DO	-0.9592	0.0000	32
	CLF-CLT	0.9752	0.0000	36
	LOG[acid-fast]-DATE	0.7920	0.0000	23
	ENDOT-ENDOF	0.8804	0.0000	20
TI1 & TI2	Temp-DO	-0.9710	0.0000	25
	CLF-CLT	0.9292	0.0000	28
	Turb-DATE	-0.7279	0.0000	26
	LOG[acid-fast]-DATE	0.7738	0.0001	20
	ENDOT-ENDOF	0.8671	0.0001	14
TI1 & TI3	pH-LOG[acid-fast]	0.7364	0.0063	12
	Temp-DO	-0.9642	0.0000	20
	CLF-CLT	0.9756	0.0000	22
	LOG[SPC]-ENDOF	0.8202	0.0238	7
	LOG[acid-fast]-DATE	0.8407	0.0001	15
	ENDOT-ENDOF	0.9114	0.0001	11
TI2 & TI3	pH-Temp	-0.8418	0.0000	22
	pH-DO	0.8527	0.0000	19
	Temp-DO	-0.8248	0.0000	19
	CLF-CLT	0.9890	0.0000	22
	LOG[m-SPC]-ENDOT	0.7473	0.0206	9
	LOG[acid-fast]-DATE	0.7397	0.0093	11
	ENDOT-ENDOF	0.9684	0.0000	15

TI - Influent

TABLE 34. SIGNIFICANT TWO-WAY CORRELATION COEFFICIENTS FOR THE COMBINED STATION T3 DATA FOR ALL THREE EXPERIMENTS

Data Set	Variables	Correlation Coefficient	Significance	N
ALL	Temp-DO	-0.8878	0.0000	32
	Temp-LOG[m-SPC]	-0.7159	0.0000	26
	DO-LOG[m-SPC]	0.7787	0.0000	24
	LOG[SPC]-LOG[m-SPC]	0.7541	0.0001	22
	ENDOT-ENDOF	0.9470	0.0000	19
T31 & T32	Temp-DO	-0.8600	0.0000	25
	Temp-LOG[m-SPC]	-0.8369	0.0000	23
	DO-LOG[m-SPC]	0.8668	0.0000	21
	LOG[SPC]-LOG[m-SPC]	0.7758	0.0001	20
	ENDOT-ENDOF	0.9485	0.0000	14
T31 & T33	Temp-DO	-0.9712	0.0000	20
	Turb-LOG[SPC]	-0.7005	0.0112	12
	DO-LOG[m-SPC]	0.7251	0.0076	12
	ENDOT-ENDOF	0.9886	0.0000	10
T32 & T33	LOG[SPC]-LOG[m-SPC]	0.9007	0.0000	14
	LOG[m-SPC]-LOG[acid-fast]	-0.7616	0.0171	9
	ENDOT-ENDOF	0.8601	0.0001	14

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TABLE 35. SIGNIFICANT TWO-WAY CORRELATION COEFFICIENTS FOR EXPERIMENT #3 OF THE GAC PILOT PLANT

Data Set	Variables	Correlation Coefficient	Significance	N
All	pH-Temp	-0.7893	0.0000	40
	pH-DO	0.8224	0.0000	35
	pH-DATE	0.7796	0.0000	40
	Temp-DO	-0.9309	0.0000	35
	Temp-DATE	-0.9871	0.0000	40
	Temp-ENDOF	-0.7626	0.0000	32
	CLF-CLT	0.9733	0.0000	40
	CLT-LOG[SPC]	-0.7850	0.0000	29
	CLT-LOG[m-SPC]	-0.7726	0.0000	25
	DO-DATE	0.9047	0.0000	35
	DO-ENDOF	0.8131	0.0000	27
	DATE-ENDOF	0.7092	0.0000	32
	LOG[SPC]-LOG[m-SPC]	0.9430	0.0000	20
	ENDOT-ENDOF	0.9590	0.0000	28
TI & T1	pH-Temp	-0.9415	0.0000	16
	pH-DO	0.9099	0.0000	14
	pH-DATE	0.8969	0.0000	16
	pH-LOG[SPC]	0.7593	0.0067	11
	pH-ENDOF	0.8220	0.0006	13
	Temp-DO	-0.9164	0.0000	14
	Temp-LOG[SPC]	-0.7596	0.0067	11
	Temp-ENDOF	-0.8044	0.0009	13
	CLF-CLT	0.9675	0.0000	16
	DO-DATE	0.8761	0.0000	14
	DO-LOG[SPC]	0.7539	0.0189	9
	DO-ENDOT	0.8003	0.0096	9
	DO-ENDOF	0.9052	0.0001	11
	DATE-LOG[SPC]	0.7400	0.0092	11
	DATE-ENDOF	0.7576	0.0027	13
	ENDOT-ENDOF	0.9861	0.0000	11
T2,T3 & T4	pH-Temp	-0.7462	0.0000	24
	pH-CLT	0.7432	0.0000	24
	pH-DO	0.8133	0.0000	21
	pH-DATE	0.7516	0.0000	24
	Temp-DO	-0.9439	0.0000	21
	Temp-ENDOF	-0.7625	0.0001	19
	CLT-DO	0.7845	0.0000	21
	CLT-DATE	0.7190	0.0001	24
	CLT-LOG[acid-fast]	0.7432	0.0346	8
	DO-DATE	0.9270	0.0000	21

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TABLE 35. (continued)

Data Set	Variables	Correlation Coefficient	Significance	N
	DO-ENDOF	0.7959	0.0002	16
	DATE-ENDOF	0.7044	0.0008	19
	LOG[SPC]-LOG[m-SPC]	0.8616	0.0003	12
	LOG[SPC]-ENDOT	-0.7269	0.0049	13
	ENDOT-ENDOF	0.9449	0.0000	17
TI	pH-Temp	-0.9306	0.0008	8
	pH-DO	0.9025	0.0054	7
	pH-DATE	0.8833	0.0036	8
	pH-ENDOF	0.8716	0.0106	7
	Temp-DO	-0.9077	0.0047	7
	Temp-ENDOF	-0.7874	0.0355	7
	CLF-CLT	0.9910	0.0000	8
	Turb-LOG[m-SPC]	1.0000	-	3
	DO-DATE	0.8638	0.0122	7
	DO-LOG[acid-fast]	1.0000	-	2
	DO-ENDOF	0.8958	0.0157	6
	DATE-LOG[acid-fast]	0.9997	0.0144	3
	LOG[m-SPC]-LOG[acid-fast]	-1.0000	-	2
	LOG[m-SPC]-ENDOT	0.9662	0.0338	4
	ENDOT-ENDOF	0.9913	0.0001	6
T1	pH-Temp	-0.9662	0.0001	8
	pH-DO	0.9327	0.0022	7
	pH-DATE	0.9235	0.0011	8
	pH-LOG[SPC]	0.9583	0.0026	6
	pH-LOG[acid-fast]	1.0000	-	2
	pH-ENDOF	0.8538	0.0305	6
	Temp-DO	-0.9253	0.0028	7
	Temp-LOG[SPC]	-0.9415	0.0050	6
	Temp-LOG[acid-fast]	-1.0000	-	2
	Temp-ENDOF	-0.8795	0.0209	6
	CLF-CLT	0.9830	0.0000	8
	CLF-LOG[acid-fast]	-1.0000	-	2
	CLT-LOG[acid-fast]	-1.0000	-	2
	Turb-LOG[acid-fast]	1.0000	-	2
	Turb-ENDOT	0.9886	0.0114	4
	Turb-ENDOF	0.9917	0.0009	5
	DO-DATE	0.8887	0.0075	7
	DO-LOG[SPC]	0.9901	0.0012	5
	DO-LOG[acid-fast]	1.0000	-	2
	DO-ENDOT	0.9563	0.0437	4
	DO-ENDOF	0.9698	0.0063	5
	DATE-LOG[SPC]	0.8967	0.0154	6

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TABLE 35. (continued)

Data Set	Variables	Correlation Coefficient	Significance	N
	DATE-LOG[acid-fast]	1.0000	-	2
	DATE-ENDOF	0.8485	0.0327	6
	LOG[SPC]-ENDOF	0.9346	0.0199	5
	LOG[m-SPC]-LOG[acid-fast]	-1.0000	-	2
	LOG[m-SPC]-ENDOT	-0.9647	0.0079	5
	LOG[m-SPC]-ENDOF	-0.9685	0.0067	5
	LOG[acid-fast]-ENDOT	1.0000	-	2
	LOG[acid-fast]-ENDOF	1.0000	-	2
	ENDOT-ENDOF	0.9877	0.0016	5
T2	pH-Temp	-0.8292	0.0109	8
	pH-CLT	0.7822	0.0218	8
	pH-DO	0.8875	0.0077	7
	pH-DATE	0.8430	0.0086	8
	Temp-DO	-0.9496	0.0011	7
	DO-DATE	0.9284	0.0025	7
	DO-LOG[acid-fast]	1.0000	-	2
	DO-ENDOF	0.8241	0.0437	6
	LOG[SPC]-LOG[m-SPC]	0.8802	0.0207	6
	LOG[SPC]-LOG[acid-fast]	-1.0000	-	2
	LOG[m-SPC]-LOG[acid-fast]	-1.0000	-	2
	ENDOT-ENDOF	0.9824	0.0005	6
T3	pH-Temp	-0.8943	0.0027	8
	pH-DO	0.9274	0.0026	7
	pH-DATE	0.8267	0.0114	8
	pH-LOG[SPC]	-0.9310	0.0070	6
	pH-LOG[acid-fast]	1.0000	-	2
	pH-ENDOT	0.9580	0.0103	5
	pH-ENDOF	0.9341	0.0201	5
	Temp-CLT	-0.7725	0.0246	8
	Temp-DO	-0.9497	0.0011	7
	Temp-LOG[SPC]	0.8201	0.0456	6
	Temp-LOG[acid-fast]	-1.0000	-	2
	CLF-LOG[acid-fast]	-1.0000	-	2
	CLT-DO	0.8491	0.0156	7
	CLT-DATE	0.8022	0.0166	8
	CLT-LOG[acid-fast]	1.0000	-	2
	Turb-LOG[acid-fast]	1.0000	-	2
	DO-DATE	0.9299	0.0024	7
	DO-LOG[acid-fast]	1.0000	-	2
	DATE-LOG[acid-fast]	1.0000	-	2
	LOG[SPC]-LOG[m-SPC]	1.0000	-	2
	LOG[SPC]-LOG[acid-fast]	-1.0000	-	2

continued

TABLE 35. (continued)

Data Set	Variables	Correlation Coefficient	Significance	N
	LOG[acid-fast]-ENDOT	1.0000	-	2
	LOG[acid-fast]-ENDOF	1.0000	-	2
	ENDOT-ENDOF	0.9948	0.0004	5
T4	pH-Temp	-0.7267	0.0412	8
	pH-CLT	0.7674	0.0262	8
	pH-DO	0.8414	0.0176	7
	pH-DATE	0.7624	0.0278	8
	Temp-CLF	-0.7448	0.0340	8
	Temp-CLT	-0.8031	0.0164	8
	Temp-DO	-0.9341	0.0021	7
	Temp-ENDOF	-0.8257	0.0221	7
	CLF-DATE	0.7529	0.0311	8
	CLF-ENDOF	0.8085	0.0277	7
	CLT-DO	0.8352	0.0193	7
	CLT-DATE	0.8475	0.0079	8
	DO-DATE	0.9243	0.0029	7
	DO-LOG[acid-fast]	-1.0000	-	2
	DATE-ENDOF	0.7797	0.0387	7
	LOG[SPC]-LOG[m-SPC]	1.0000	-	2
	LOG[SPC]-ENDOT	-0.9629	0.0371	4
	LOG[m-SPC]-LOG[acid-fast]	1.0000	-	2
	ENDOT-ENDOF	0.9335	0.0065	6

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TABLE 36. SIGNIFICANT TWO-WAY CORRELATION COEFFICIENTS FOR EXPERIMENT #2 OF THE GAC PILOT PLANT

Data Set	Variables	Correlation Coefficient	Significance	N
ALL	Temp-DATE	0.9888	0.0000	70
	CLF-CLT	0.9129	0.0000	70
	DO-ENDOF	-0.7428	0.0000	40
	ENDOT-ENDOF	0.8389	0.0000	44
TI & T1	pH-DO	0.7793	0.0000	24
	Temp-DO	-0.8924	0.0000	24
	CLF-CLT	0.7535	0.0000	28
	DO-DATE	-0.9211	0.0000	24
	DO-ENDOF	-0.8263	0.0001	16
	ENDOT-ENDOF	0.8346	0.0000	18
T2, T3 & T4	DO-ENDOF	-0.7411	0.0000	24
	ENDOT-ENDOF	0.8334	0.0000	26
TI	pH-Temp	-0.7338	0.0028	14
	pH-DO	0.8473	0.0005	12
	pH-DATE	-0.7581	0.0017	14
	pH-LOG[acid-fast]	-0.9089	0.0018	8
	Temp-DO	-0.8879	0.0001	12
	Temp-LOG[m-SPC]	-0.7722	0.0247	8
	CLF-CLT	0.9532	0.0000	14
	DO-DATE	-0.9167	0.0000	12
	DO-ENDOF	-0.8460	0.0081	8
	DATE-LOG[m-SPC]	-0.7689	0.0258	8
	LOG[m-SPC]-LOG[acid-fast]	-0.9982	0.0380	3
	ENDOT-ENDOF	0.8150	0.0074	9
T1	pH-DO	0.7287	0.0072	12
	Temp-DO	-0.8979	0.0001	12
	DO-DATE	-0.9261	0.0000	12
	DO-ENDOF	-0.8038	0.0162	8
	ENDOT-ENDOF	0.8618	0.0028	9
T2	Temp-CLT	0.7026	0.0051	14
	CLT-DATE	0.7179	0.0038	14
	ENDOT-ENDOF	0.9820	0.0000	8
T3	pH-ENDOF	-0.7227	0.0278	9
	Temp-CLT	0.8061	0.0005	14
	CLF-LOG[acid-fast]	-0.7159	0.0458	8
	CLT-DATE	0.7994	0.0006	14
	DO-ENDOF	-0.8341	0.0100	8
	LOG[SPC]-LOG[m-SPC]	0.7465	0.0053	12
	ENDOT-ENDOF	0.8366	0.0049	9
T4	pH-CLT	-0.8463	0.0001	14
	pH-ENDOF	-0.7147	0.0305	9
	Temp-CLT	0.7523	0.0019	14
	CLT-DATE	0.7498	0.0020	14
	Turb-ENDOF	-0.7714	0.0149	9

continued

TABLE 36 (continued)

Data Set	Variables	Correlation Coefficient	Significance	N
	DO-ENDOF	-0.8065	0.0156	8
	LOG[acid-fast]-ENDOF	0.9375	0.0057	6
	ENDOT-ENDOF	0.7096	0.0322	9

TI - Influent

TABLE 37. SIGNIFICANT TWO-WAY CORRELATION COEFFICIENTS FOR EXPERIMENT #1 OF THE GAC PILOT PLANT

Data Set	Variables	Correlation Coefficient	Significance	N
All	Temp-Turb	-0.7629	0.0000	64
	Temp-DATE	0.8822	0.0000	75
	CLF-CLT	0.9287	0.0000	70
	CLF-LOG[m-SPC]	-0.8361	0.0000	32
	CLT-LOG[m-SPC]	-0.8803	0.0000	32
	Turb-DATE	-0.8186	0.0000	64
	LOG[acid-fast]-DATE	0.7290	0.0000	57
	ENDOF-ENDOT	0.9031	0.0000	26
TI & T1	Temp-Turb	-0.7102	0.0000	26
	Temp-DO	-0.7083	0.0001	26
	CLF-CLT	0.8348	0.0000	28
	CLT-ENDOT	-0.7443	0.0055	12
	Turb-DATE	-0.7976	0.0000	26
	LOG[acid-fast]-DATE	0.7566	0.0000	25
T2, T3 & T4	Temp-Turb	-0.8069	0.0000	38
	Turb-DATE	-0.8388	0.0000	38
	LOG[acid-fast]-DATE	0.7127	0.0000	32
	ENDOF-ENDOT	0.9428	0.0000	16
TI	Temp-Turb	-0.7831	0.0015	13
	Temp-DO	-0.7072	0.0069	13
	CLF-CLT	0.9046	0.0000	14
	CLF-ENDOF	-0.8841	0.0465	5
	CLF-ENDOT	-0.9830	0.0004	6
	Turb-LOG[acid-fast]	-0.7749	0.0031	12
	Turb-DATE	-0.8704	0.0001	13
	LOG[SPC]-ENDOF	1.0000	--	2
	LOG[m-SPC]-DATE	0.9454	0.0152	5
	LOG[acid-fast]-DATE	0.8233	0.0010	12
	ENDOF-ENDOT	0.9108	0.0318	5
T1	Temp-DO	-0.7190	0.0056	13
	CLF-CLT	0.8484	0.0001	14
	CLT-ENDOT	-0.8748	0.0225	6
	Turb-DO	0.7479	0.0081	11
	Turb-DATE	-0.7176	0.0057	13
	LOG[SPC]-LOG[m-SPC]	-0.9790	0.0210	4
	LOG[acid-fast]-ENDOF	0.8923	0.0417	5
T2	Temp-Turb	-0.7964	0.0011	13
	Temp-DO	-0.7090	0.0067	13
	Temp-LOG[m-SPC]	0.7842	0.0212	8
	CLT-DATE	0.7417	0.0024	14
	Turb-DATE	-0.8244	0.0005	13
	LOG[SPC]-LOG[acid-fast]	0.7812	0.0045	11
	LOG[acid-fast]-DATE	0.7374	0.0062	12
	LOG[m-SPC]-DATE	0.8050	0.0159	8

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TABLE 37 (continued)

Date Set	Variables	Correlation Coefficient	Significance	N
T3	pH-LOG[m-SPC]	-0.7333	0.0384	8
	Temp-Turb	-0.7956	0.0020	12
	Temp-LOG[SPC]	0.8696	0.0011	10
	CLT-LOG[SPC]	0.7158	0.0199	10
	CLT-DATE	0.7176	0.0039	14
	Turb-DO	0.7932	0.0062	10
	Turb-LOG[SPC]	-0.7462	0.0335	8
	Turb-DATE	-0.8372	0.0007	12
	DO-LOG[SPC]	-0.7004	0.0241	10
	LOG[SPC]-DATE	0.9348	0.0001	10
	LOG[m-SPC]-DATE	0.7847	0.0123	9
	ENDOF-ENDOT	0.9971	0.0002	5
T4	pH-LOG[acid-fast]	-0.9321	0.0007	8
	Temp-CLT	0.7626	0.0015	14
	Temp-Turb	-0.8329	0.0004	13
	Turb-DATE	-0.8576	0.0002	13
	LOG[m-SPC]-DATE	0.7428	0.0348	8
	LOG[acid-fast]-DATE	0.7743	0.0086	10
	ENDOF-ENDOT	0.9932	0.0007	5

TI - Influent

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TABLE 38. TWO-WAY ANOVAS (TIME AND STATION) ON BACTERIAL PARAMETERS FOR TROY

Variable	Data Set Experiment #1 Time	 Experiment #1 Station	 Experiment #2 Time	 Experiment #2 Station	 Experiment #3 Time	 Experiment #3 Station	 T3 Combined Time	 T3 Combined Station	 TI Combined Time	 TI Combined Station
LOG[SPC]	S	S	S	NS	S	S	NS	NS	NS	NS
LOG[m-SPC]	S	S	NS	S	S	S	ID	ID	ID	ID
LOG[acid-fast]	S	NS	NS	NS	NS	NS	ID	ID	ID	ID
Total Endotoxins	S	NS	S	S	S	S	ID	ID	ID	ID
Free Endotoxins	S	NS	S	NS	S	S	ID	ID	ID	ID

S = Significant ≤ 0.05
NS = Not significant
ID = Insufficient data
TI = Influent

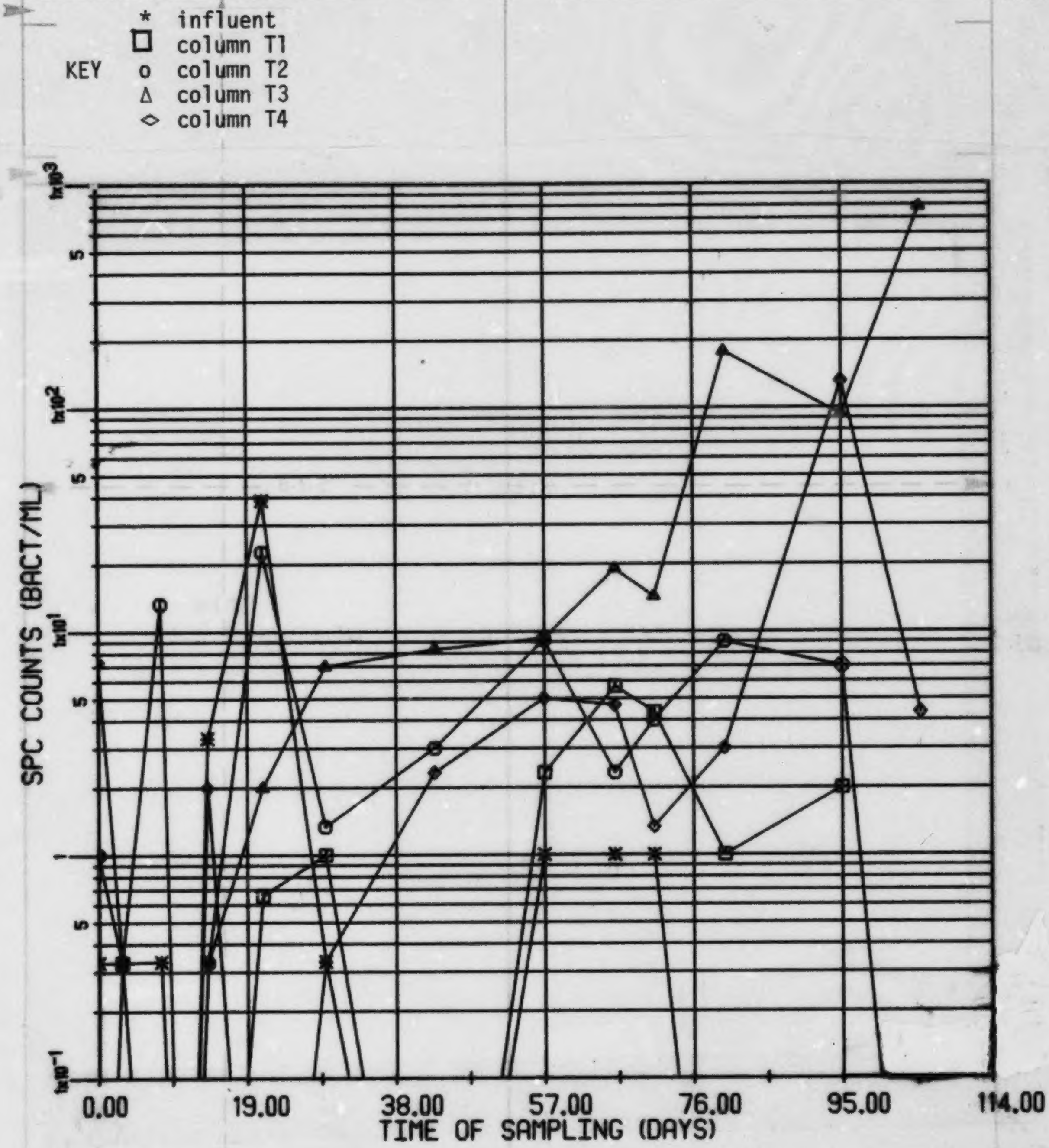

Figure 24. SPC counts versus time of sampling for experiment #1 from the Troy G.A.C. pilot unit.

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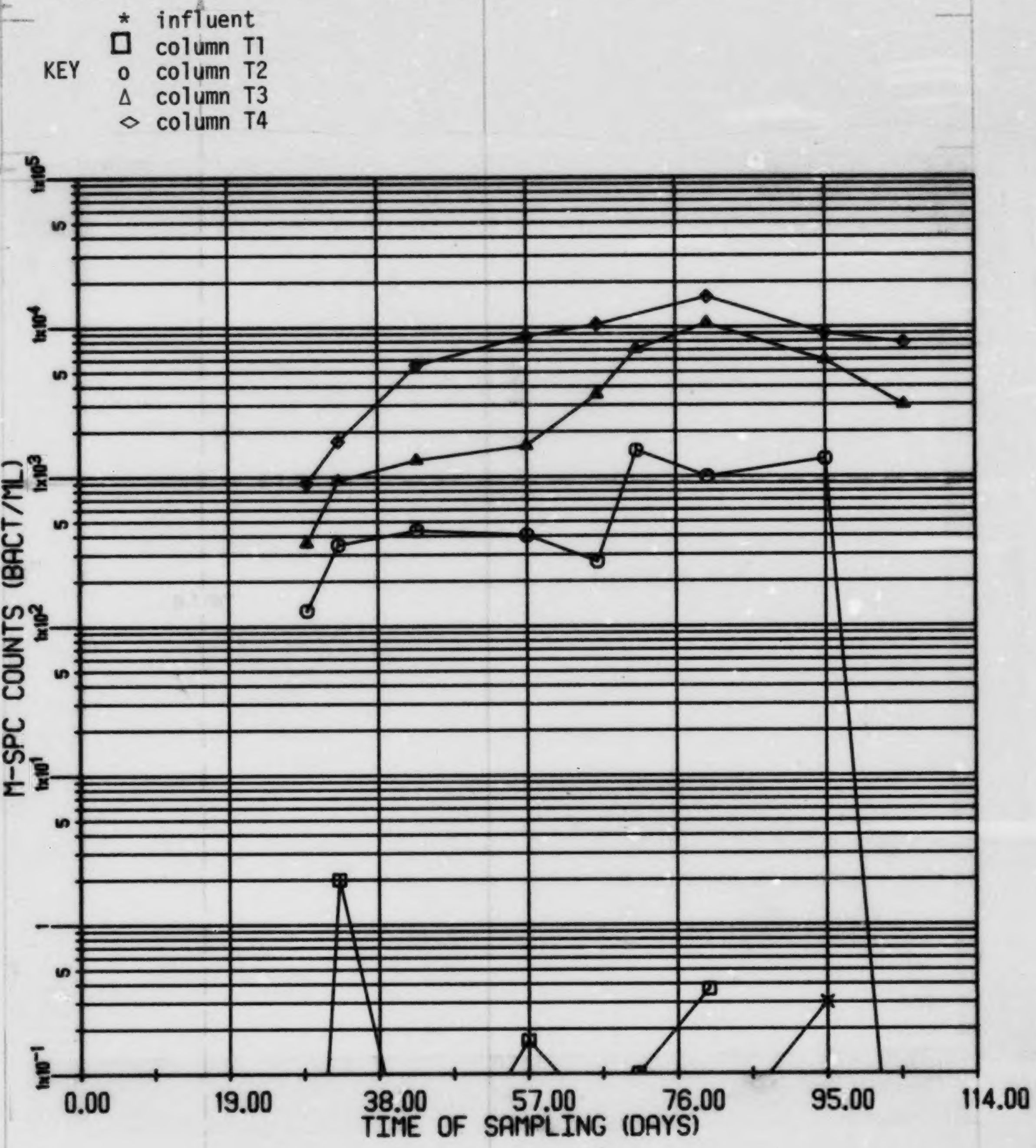

Figure 25. M-SPC counts versus time of sampling for experiment #1 from the Troy G.A.C. pilot unit.

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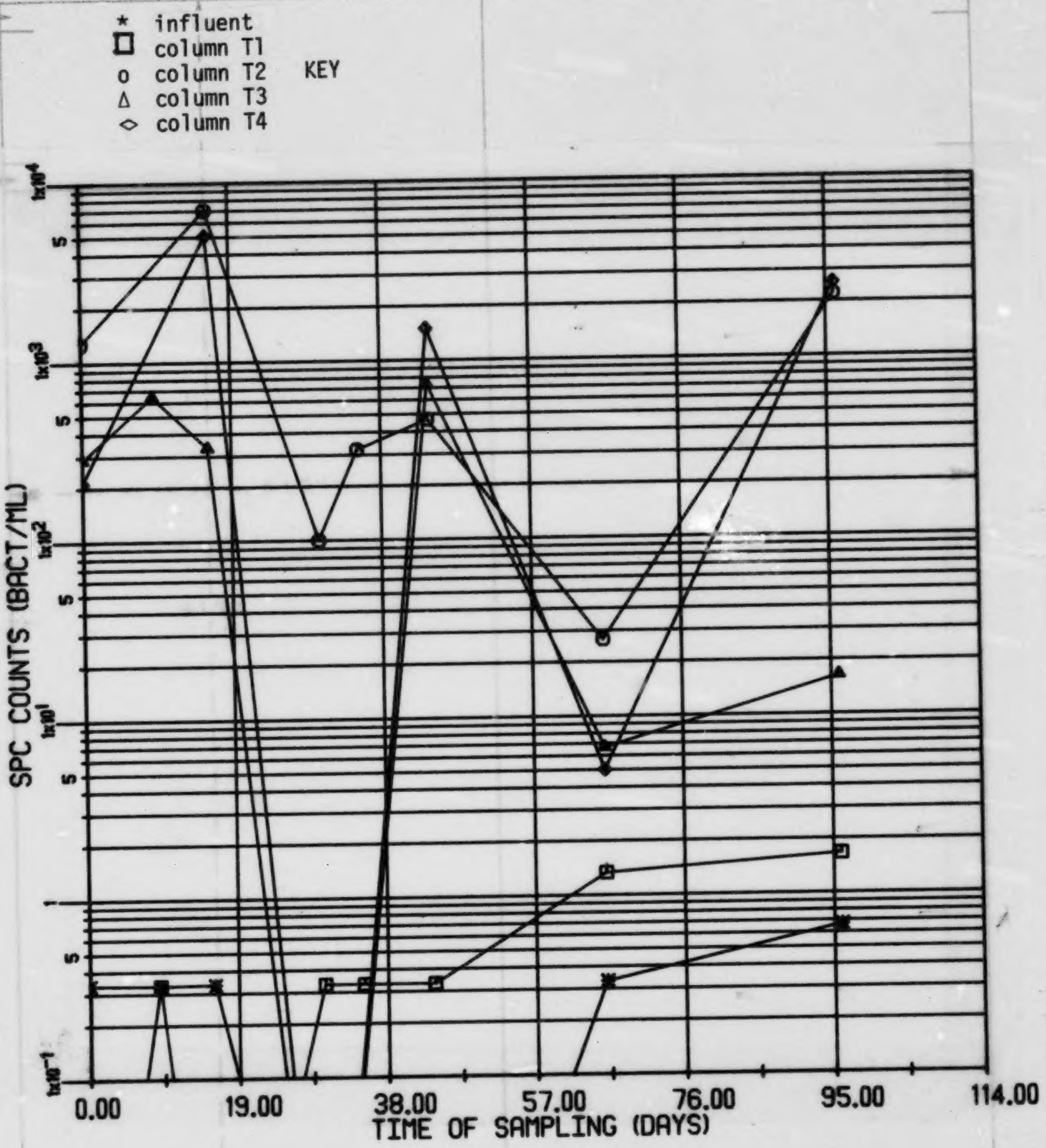

Figure 26. SPC counts versus time of sampling for experiment #3 from the Troy G.A.C. pilot unit.

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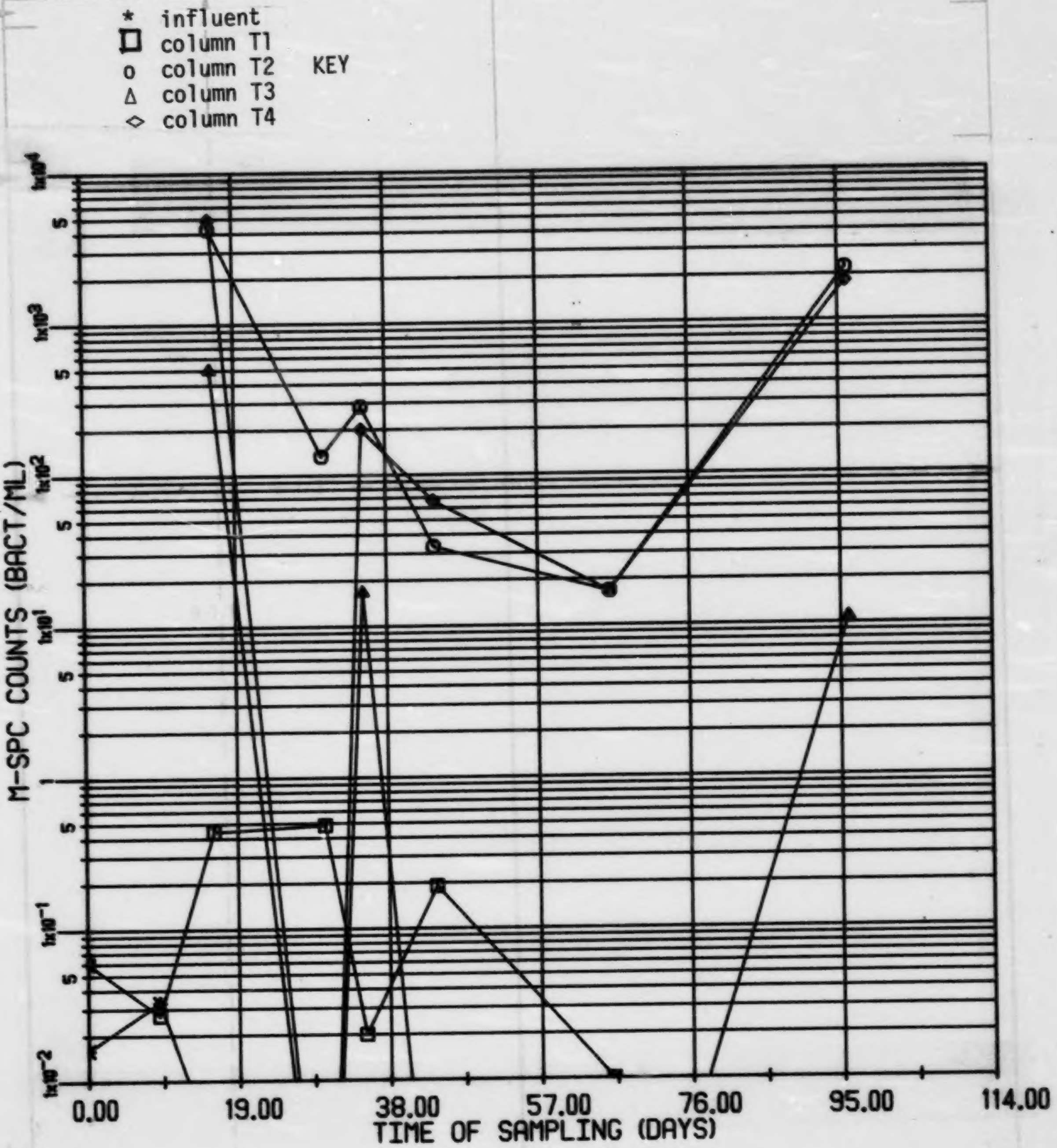

Figure 27. M-SPC counts versus time of sampling for experiment #3 from the Troy G.A.C. pilot unit.

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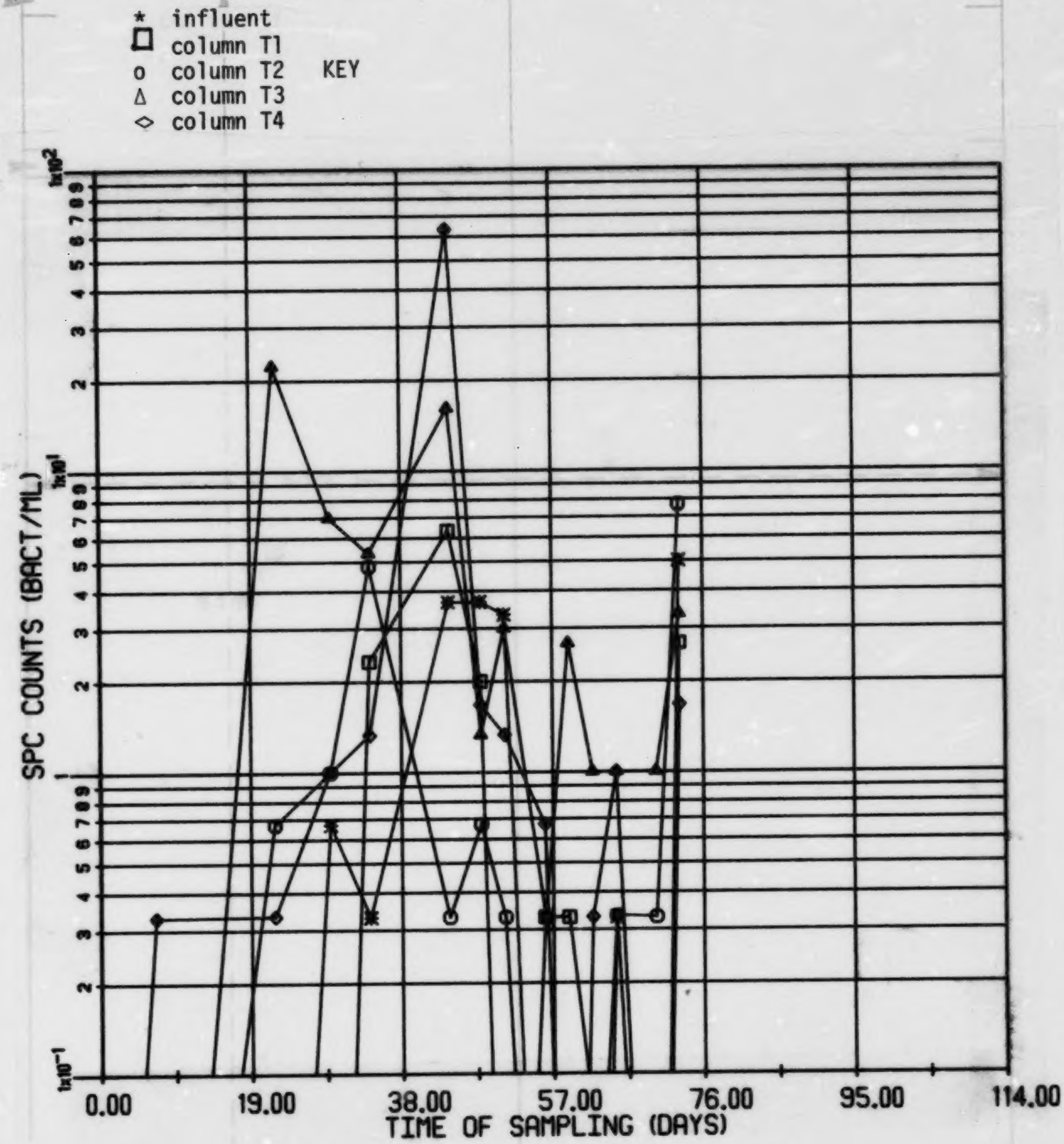

Figure 28. SPC counts versus time of sampling for experiment #2 from the Troy G.A.C. pilot unit.

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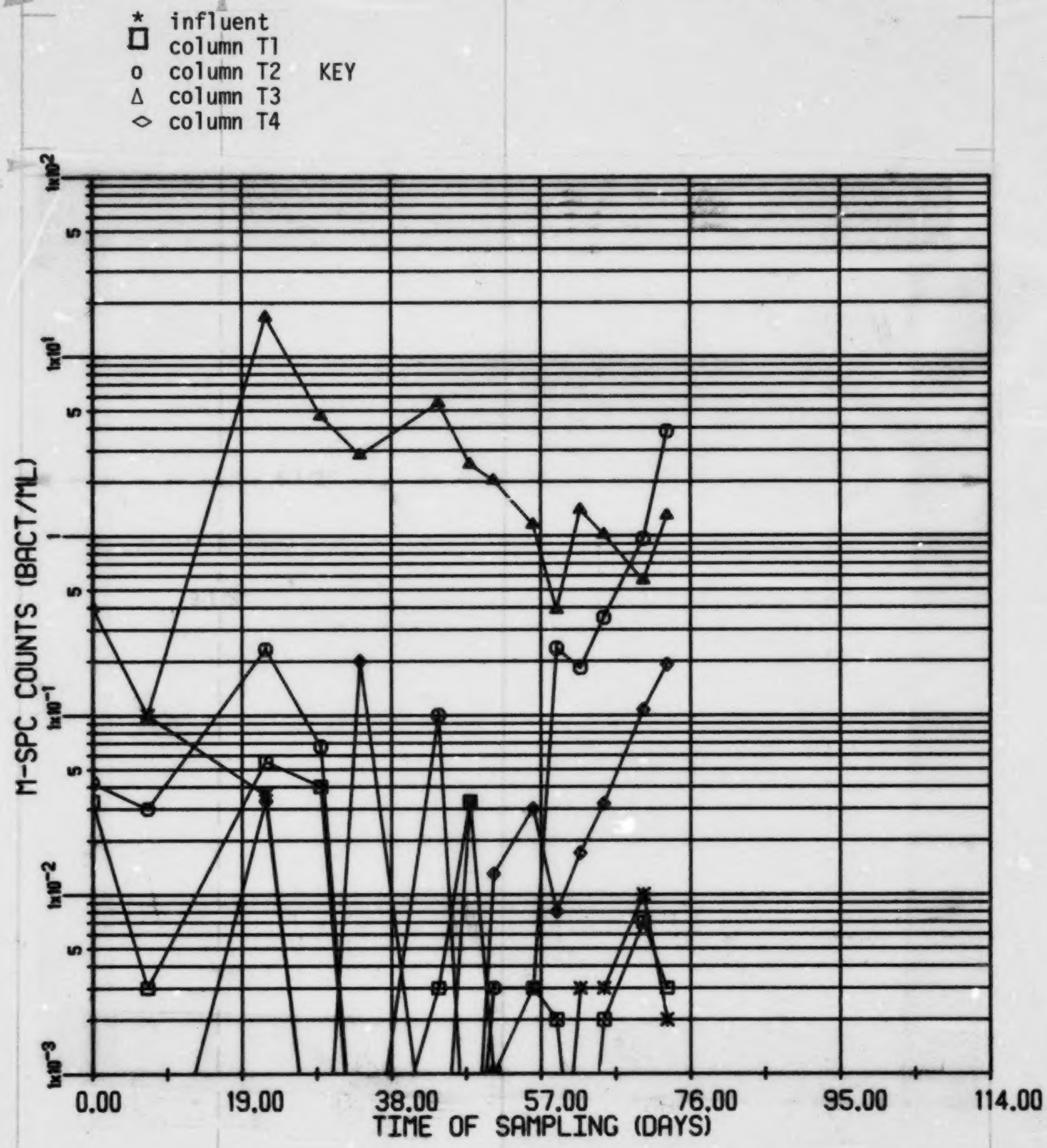

Figure 29. M-SPC counts versus time of sampling for experiment #2 from the Troy G.A.C. pilot unit.

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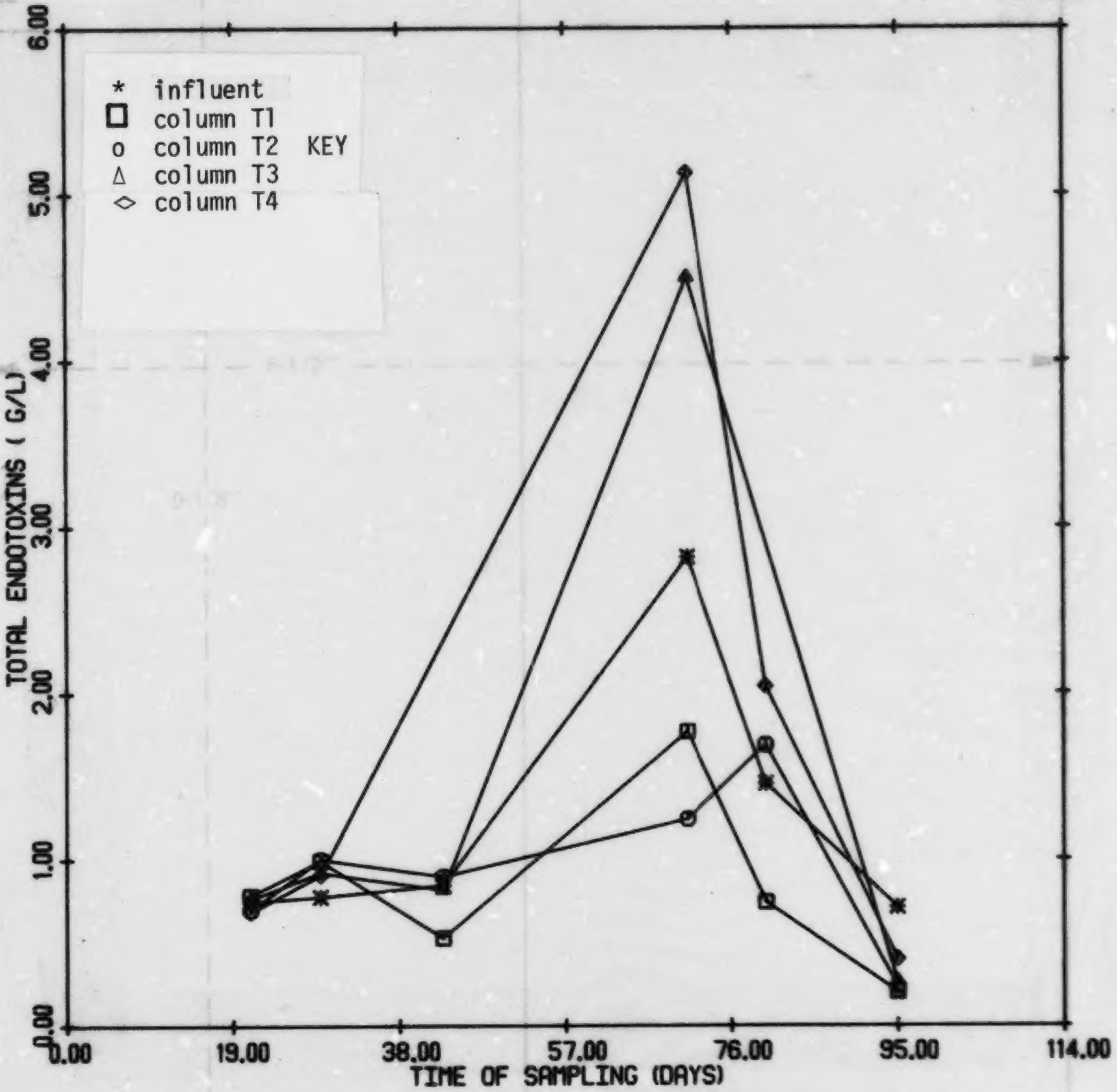

Figure 30. Total endotoxins versus time of sampling for experiment #1 from the Troy G.A.C. pilot unit.

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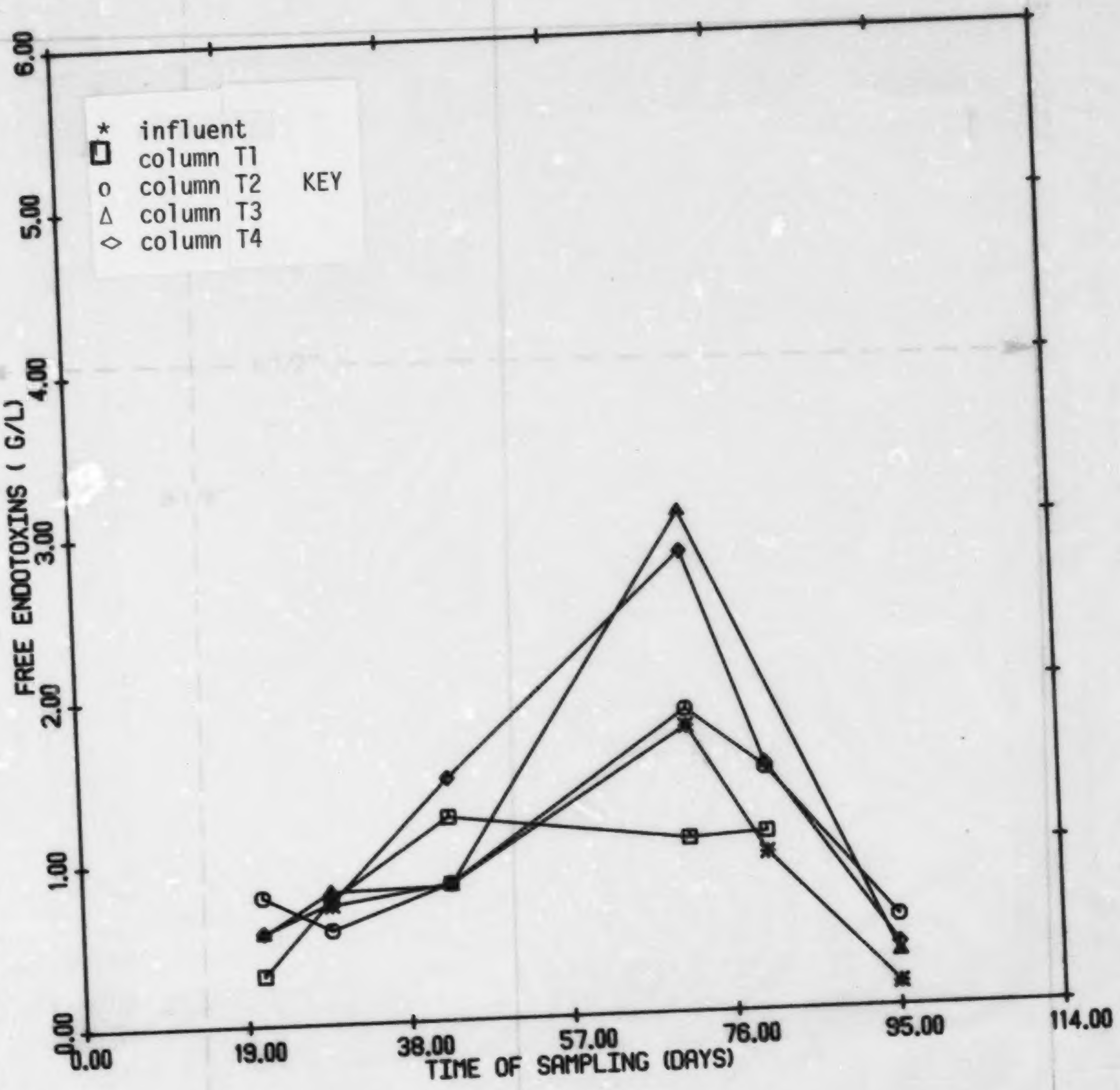

Figure 31. Free endotoxins versus time of sampling for experiment #1 from the Troy G.A.C. pilot unit.

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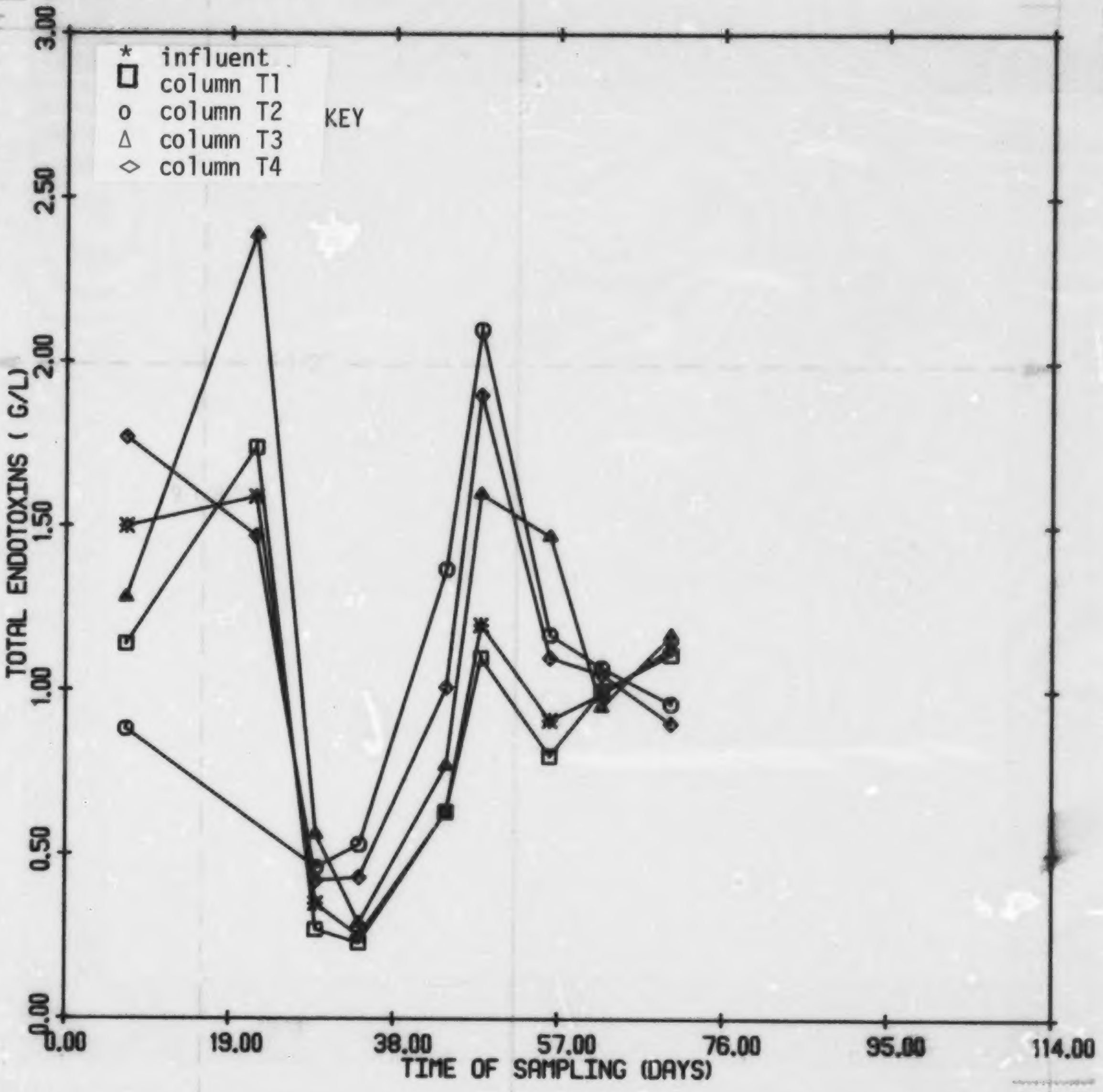

Figure 32. Total endotoxins versus time of sampling for experiment #2 from the Troy G.A.C. pilot unit.

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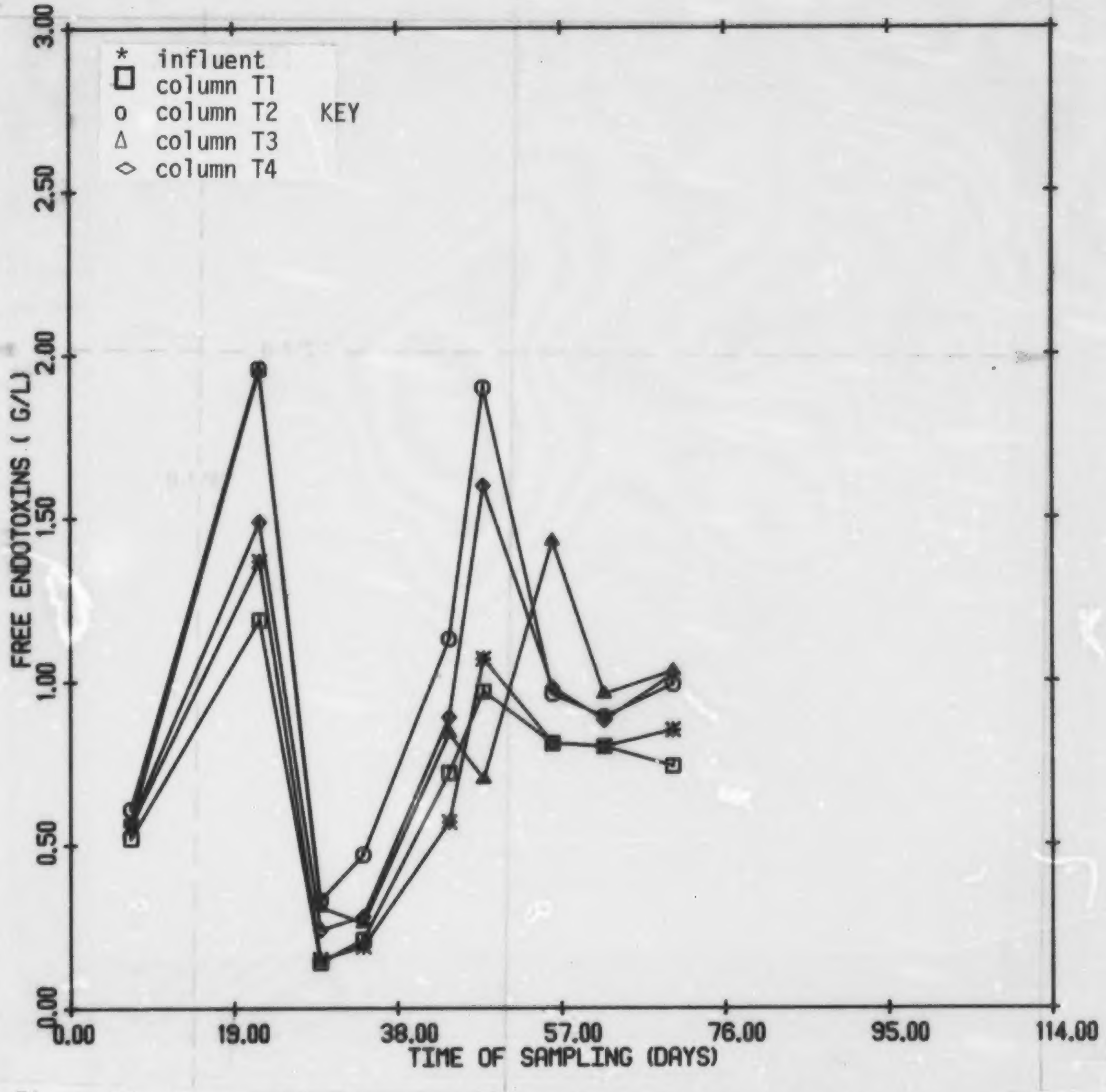

Figure 33. Free endotoxins versus time of sampling for experiment #2 from the Troy G.A.C. pilot unit.

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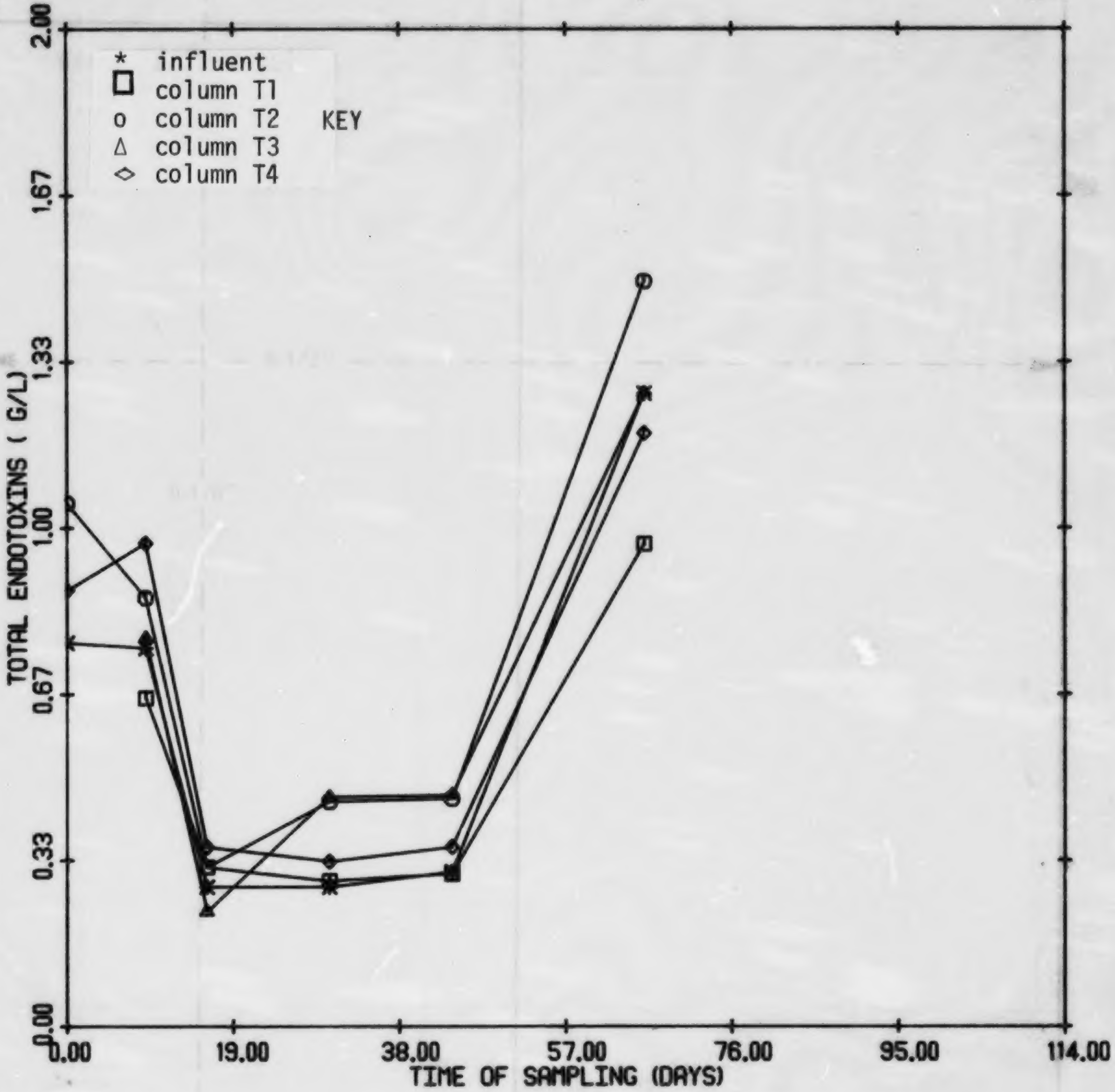

Figure 34. Total endotoxins versus time of sampling for experiment #3 from the Troy G.A.C. pilot unit.

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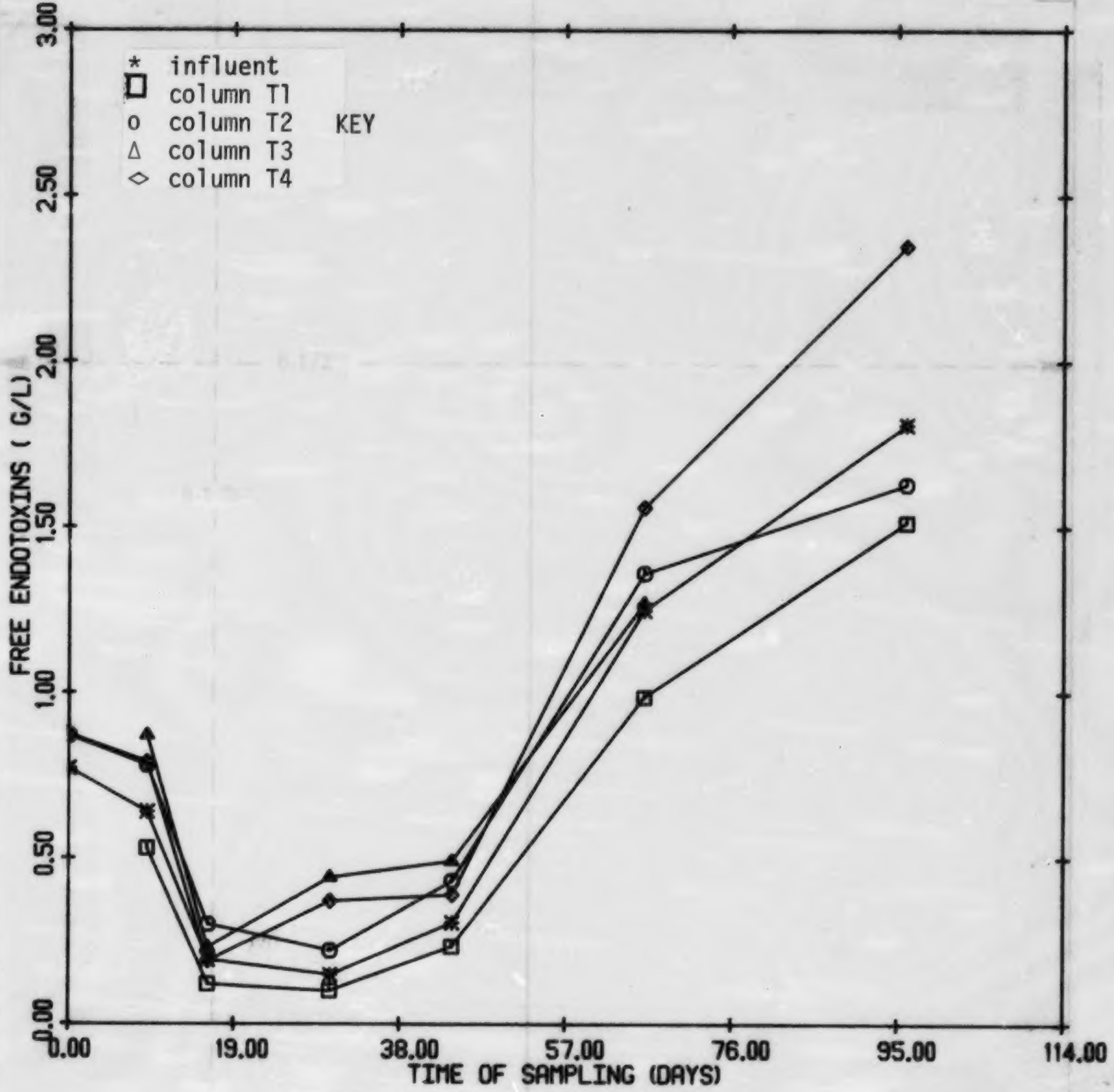

Figure 35. Free endotoxins versus time of sampling experiment #3 from the Troy G.A.C. pilot unit.

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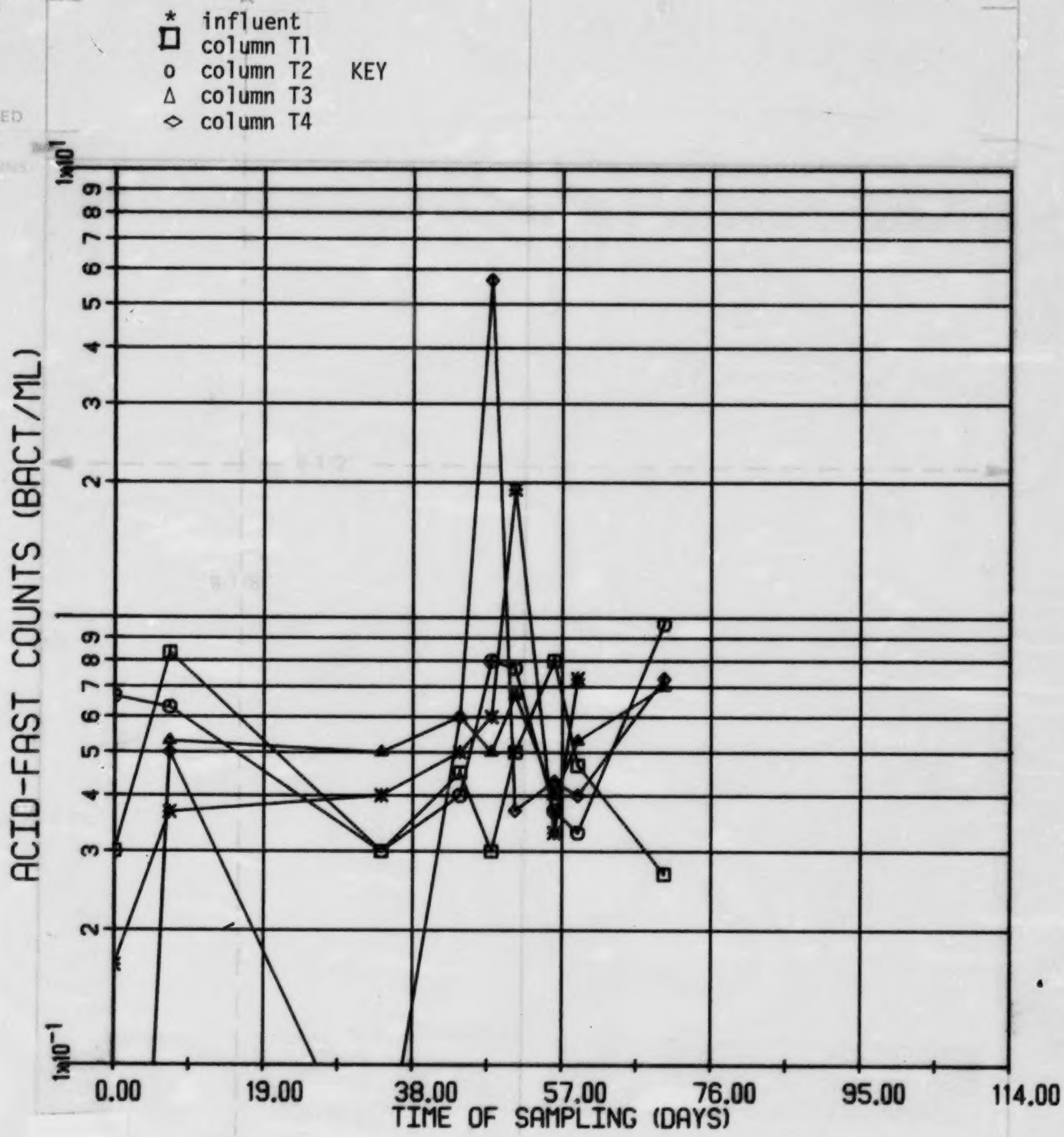

Figure 36. Acid-Fast counts versus time of sampling for experiment #2 from the Troy G.A.C. pilot unit.

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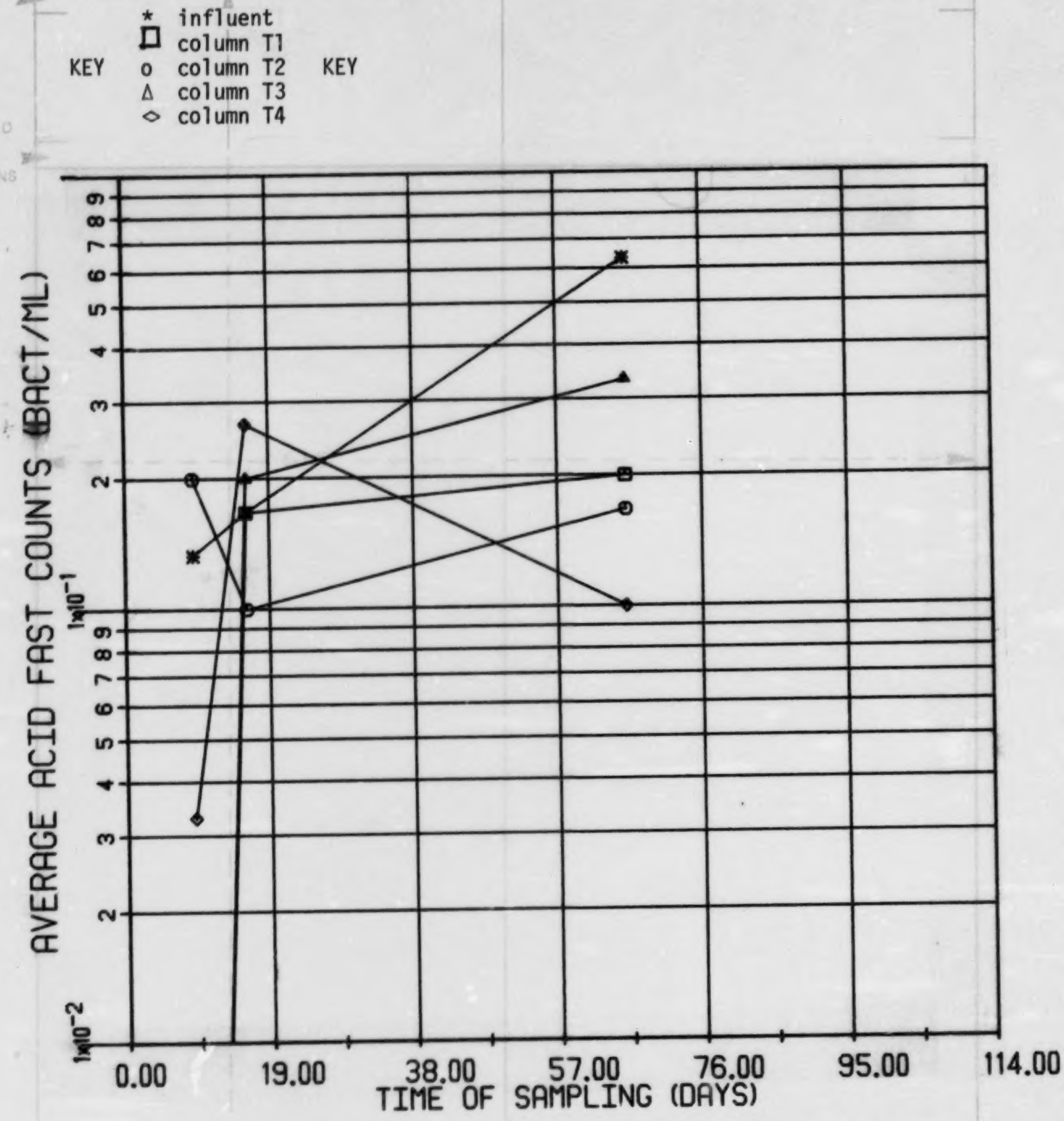

Figure 37. Acid-Fast counts versus time of sampling for experiment #3 from the Troy G.A.C. pilot unit.

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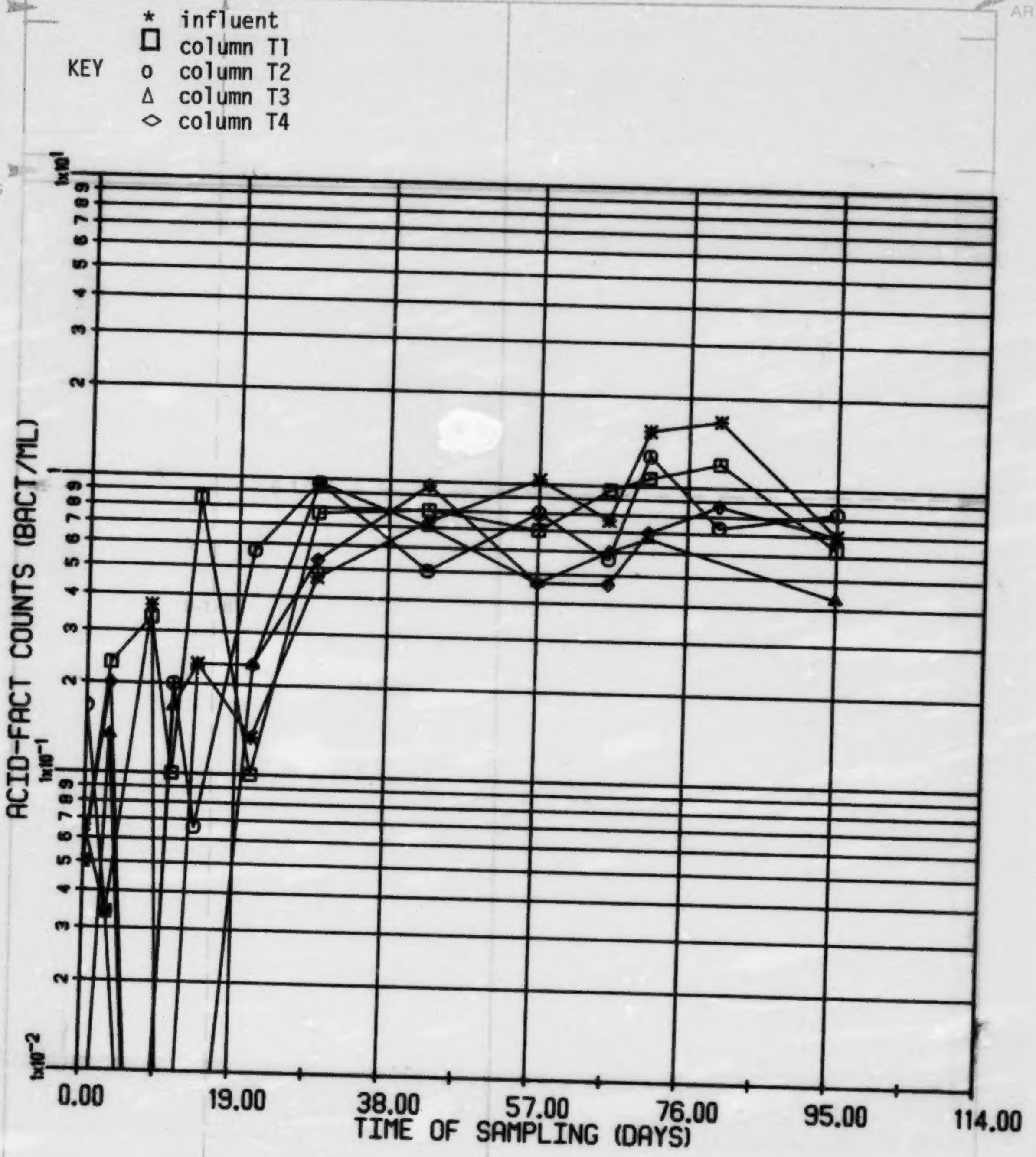

Figure 38. Acid-Fast counts versus time of sampling for experiment #1 from the Troy G.A.C. pilot unit.

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From the combinations anovas of all of the influent and all of the station T3's values, were obtained for only SPC and in both cases time and station were not significant. No anovas could be performed for the remaining bacterial parameters since there were insufficient data available for analysis.

Bacteria on Carbon

The number of bacteria per gram of wet carbon varied with each experiment (Table 39) and in experiment 3 this also varied with station. Generally, the difference of bacteria per gram of wet carbon between experiments 1 and 2 was approximately five orders of magnitude for both SPC and m-SPC levels. Since in experiment 1 the plates were completely covered at the highest dilution only an estimate for these values could be established. Experiment 2 showed that the values for both SPC and m-SPC were similar. It should also be noted that T3t and T3b (Table 39) for both experiments 2 and 3 had very similar values for SPC and m-SPC which is significant since station T3 acted as a control for the GAC containing columns because its operating parameters for each experiment were kept constant.

Experiment 3, however, showed an increase in the number of bacteria per gram of wet carbon with an increasing amount of free chlorine for both SPC and m-SPC values.

Some variation was also seen in comparing the top of the columns' bacteria per gram of wet carbon to that of the column's bottom. However, no trend between the top and bottom of the same column's bacteria per gram of wet carbon seemed apparent.

The difference in the number of bacteria per gram of wet carbon in the GAC columns for the first two experiments could be explained from a temperature, dissolved oxygen, and/or turbidity difference between these experiments. For the first experiment, the average temperature was significantly lower, while the average dissolved oxygen and turbidity were significantly higher for the influent and effluent of each column than in the second experiment. This can be seen from the student t-tests between the station T3 data combined (Table 40) as well as with the influent data combined (Table 41) from all three experiments. Also, even though in experiment 2 the velocity of the flow ranged from 120 ml/min to 45 ml/min through 2 feet of GAC, the bacteria per gram of wet carbon for all 3 GAC columns showed no influence from the velocity. The same could also be said for variable carbon height as well. Lastly, there was a significant difference in free chlorine between the influent of both experiments 1 and 2 with the higher free chlorine value occurring to experiment 1.

Free chlorine did not seem to be a significant factor by itself. The student t-test between the influent of experiment 2 and the influent of experiment 3 (Table 41) only showed a significant difference in both total and free chlorine, with the higher values found in experiment 3. However, the bacteria per gram of wet carbon values between experiment 3 and experiment 2 for station T3 (Table 39) are very similar and are in the same order of magnitude for both SPC and m-SPC.

TABLE 39. NUMBER OF COLONY FORMING UNITS ON GAC FOR ALL THREE EXPERIMENTS

BY SPC

Column and Position	Experiment 1	 2	 3
T2t	Estimated to be approximately 10^9	4.2×10^4	3.3×10^6
T2b		-	2.3×10^6
T3t		1.5×10^4	4.2×10^4
T3b		1.9×10^4	5.6×10^4
T4t		2.0×10^4	0.4×10^5
T4b		0.2×10^4	0.4×10^6

t = top of column
b = bottom of column

BY M-SPC

Column and Position	Experiment 1	 2	 3
T2t	Estimated to be approximately 10^9	3.85×10^4	0.5×10^6
T2b		1.6×10^4	2.5×10^6
T3t		2.9×10^4	1.2×10^4
T3b		1.3×10^4	2.7×10^4
T4t		4.13×10^4	0.47×10^5
T4b		1.5×10^4	0.10×10^6

t = top of column
b = bottom of column

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TABLE 40. STUDENT t-TEST FOR COMPARING STATION T3'S DIFFERENCES BETWEEN EACH EXPERIMENT FOR THE PILOT UNIT

Variable	Exp #1 to Exp #2 Mean	Exp #1 to Exp #2 Sign.	N	Exp #1 to Exp #3 Mean	Exp #1 to Exp #3 Sign.	N	Exp #2 to Exp #3 Mean	Exp #2 to Exp #3 Sign.	N
pH	6.8091^{a} 6.8571^{b}	0.8558	11 14	6.8091^{a} 6.5962^{c}	0.0919	11 8	6.8571^{b} 6.5962^{c}	0.3874	14 8
Temp	3.8400^{a} 17.200^{b}	0.0000*	15 14	3.8400^{a} 19.237^{c}	0.0000*	15 8	17.200^{b} 19.237^{c}	0.3228	14 8
CLF	0.0000^{a} 0.007857^{b}	-	14 14	0.0000^{a} 0.00875^{c}	-	14 8	0.00786^{b} 0.00875^{c}	0.9274	14 8
CLT	0.07500^{a} 0.06071^{b}	0.5561	14 14	0.07500^{a} 0.10375^{c}	0.3224	14 8	0.06071^{b} 0.10375^{c}	0.0791	14 8
Turb	0.29000^{a} 0.12385^{b}	0.0008*	12 13	0.29000^{a} 0.09167^{c}	0.0050*	12 6	0.12385^{b} 0.09167^{c}	0.1619	13 6
DO	12.592^{a} 7.7250^{b}	0.0000*	13 12	12.592^{a} 6.8714^{c}	0.0000*	13 7	7.7250^{b} 6.8714^{c}	0.2542	12 7
LOG[SPC]	1.2101^{a} 0.43316^{b}	0.0276*	10 12	1.2101^{a} 2.1150^{c}	0.0823	10 6	0.43316^{b} 2.1150^{c}	0.0001*	12 6
LOG[m-SPC]	3.3903^{a} 0.14606^{b}	0.0000*	9 14	3.3903^{a} 1.6528^{c}	0.0013*	9 3	0.14606^{b} 1.6528^{c}	0.0016*	14 3
LOG[AF]	-0.41813^{a} -0.26277^{b}	0.1648	10 8	-0.41813^{a} -0.58826^{c}	0.4530	10 2	-0.26277^{b} -0.58826^{c}	0.0020*	8 2
Total Endotoxins	1.4526^{a} 1.1644^{b}	0.6523	5 9	1.4526^{a} 0.64080^{c}	0.3348	5 5	1.1644^{b} 0.64080^{c}	0.1201	9 5
Free Endotoxins	1.1126^{a} 0.89444^{b}	0.6233	5 9	1.1126^{a} 0.66060^{c}	0.4173	5 5	0.89444^{b} 0.66060^{c}	0.4175	9 5

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[a] Experiment #1

[b] Experiment #2

[c] Experiment #3

[*] Significance ≤ 0.05

TABLE 41. STUDENT t-TESTS FOR COMPARING THE INFLUENT DIFFERENCES BETWEEN EACH EXPERIMENT FOR THE PILOT UNIT

	Exp #1 to Exp #2			Exp #1 to Exp #3			Exp #2 to Exp #3		
Variable	Mean	Sign.	N	Mean	Sign.	N	Mean	Sign.	N
pH	6.6673^a	0.5866	11	6.6673^a	0.1751	11	6.6314^b	0.1481	14
	6.6314^b		14	6.5437^c		8	6.5437^c		8
Temp	3.8400^a	0.0000*	15	3.8400^a	0.0000*	15	17.200^b	0.3255	14
	17.200^b		14	19.225^c		8	19.225^c		8
CLF	0.38214^a	0.0119*	14	0.38214^a	0.0859	14	0.27429^b	0.0059*	14
	0.27429^b		14	0.54125^c		8	0.54125^c		8
CLT	0.50571^a	0.0720	14	0.50571^a	0.0632	14	0.42143^b	0.0080*	14
	0.42143^b		14	0.69250^c		8	0.69250^c		8
Turb	0.30692^a	0.0013*	13	0.30692^a	0.0062*	13	0.13000^b	0.1437	13
	0.13000^b		13	0.09333^c		6	0.09333^c		6
DO	13.000^a	0.0000*	13	13.000^a	0.0000*	13	8.4333^b	0.0604	12
	8.4333^b		12	7.071^c		7	7.0714^c		7
LOG[SPC]	0.02130^a	0.6342	9	0.02130^a	0.1851	9	0.17341^b	0.0364*	7
	0.17341^b		7	-0.41892^c		5	-0.41892^c		5
LOG[m-SPC]	-1.4413^a	0.1276	5	-1.4413^a	0.1488	5	-2.0837^b	0.9943	8
	-2.0837^b		8	-2.0808^c		4	-2.0808^c		4
LOG[AF]	-0.40905^a	0.6372	12	-0.40905^a	0.5400	12	-0.30826^b	0.1896	8
	-0.30826^b		8	-0.61734^c		3	-0.61734^c		3
Total Endotoxins	1.2252^a	0.4236	6	1.2252^a	0.1329	6	0.95000^b	0.1712	9
	0.95000^b		9	0.61167^c		6	0.61167^c		6
Free Endotoxins	0.88160^a	0.5127	5	0.88160^a	0.6766	5	0.70778^b	0.9277	9
	0.70778^b		9	0.73100^c		7	0.73100^c		7

---

[a] Experiment #1
[b] Experiment #2
[c] Experiment #3
[*] Significance

Moreover, comparing experiment 3 to experiment 1 for both the influent and station T3 with a student t-test (Tables 40, 41) showed the same trends as for experiment 2 versus experiment 1 mentioned above. This would indicate that lower temperatures, higher dissolved oxygen and turbidity in both the influent and the column effluent may be associated with a higher regrowth of microorganisms on GAC. Also, from experiment 3 it was seen that the bacteria per wet gram of carbon increased with increasing free chlorine values. Therefore, influents with high dissolved oxygen, turbidity, and free chlorine, and low temperature appear to assist regrowth on GAC.

Some of these observations can also be coupled to show what physio-chemical parameters aid in bacterial sloughing. Experiment 1 had the highest significant average for m-SPC for all three experiments, while experiment 2 had both the significantly lowest average m-SPC and SPC values for the GAC columns. The significantly highest SPC values were found in experiment 3.

Student t-tests for the combined influent (Table 41) and for the combined station T3 (Table 40) data seem to indicate that the low SPC averages found in experiment 1 and 2 may have arisen because both of these experiments had lower influent free chlorine than did experiment 3. It should also be noted that experiment 2 had the lowest average influent free chlorine values for all three experiments. This may show that free chlorine may play a role in bacterial sloughing from GAC.

Scanning Electron Microscopy

Figures 39-54 are scanning electron microscopy (SEM) photographs of representative samples displaying the surface of the GAC from different columns and experiments. Each photograph indicates the specific column and the location within the column. Experiment 1's SEM pictures are seen in Figures 39 through 42, while experiments 2's SEM pictures are found from Figures 43 to 47. The last remaining photographs, Figures 48 to 54 are from the third experiment.

The photographs from experiment 1, except for the photo of the blank carbon, displayed a large number of rod and cocci-shaped particles covering almost the entire carbon surface. However, the blank carbon particles, which were prepared for the SEM with the omission of the fixation-dehydration sequence, appeared completely barren of any artifacts.

From experiment 2's SEM photographs, small patches of cocci and slime-type material could be readily observed over some portions of the carbon particle's surface. Fibrous filaments were seen in both Figures 43 and 44, while large nodules were observed in Figure 45. The blank carbon particles from experiment 2 were prepared identically to the GAC column's carbon particle for the SEM. The blank carbon displayed some objects that resembled some types of artifacts previously seen on the GAC carbon particles.

Experiment 3's SEM photographs were very similar to those from the second experiment. However, no filaments or large nodules were observed. Most importantly, even after being prepared the same as the GAC carbon particles, the blank carbon had numberous patches of material over all its surface.

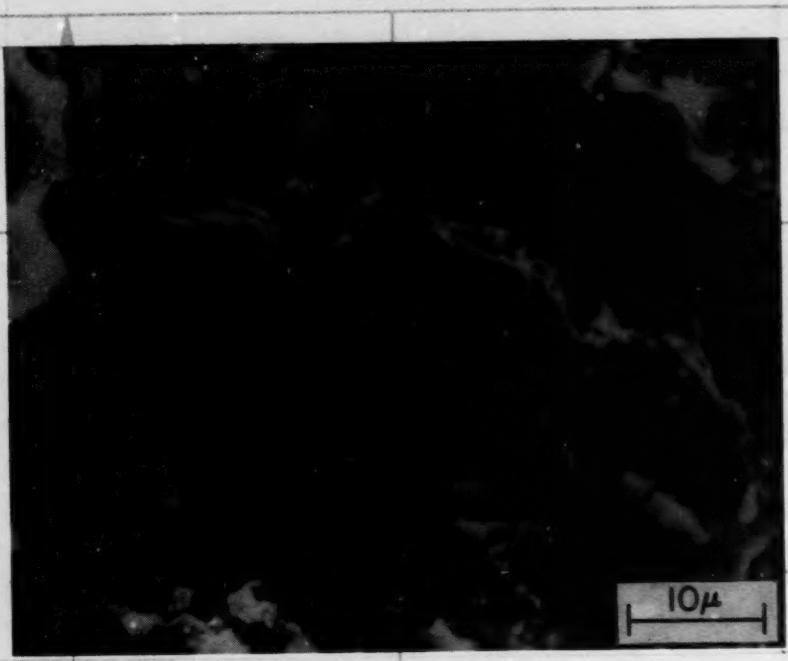

Figure 39. Run 1, blank carbon (x2000).

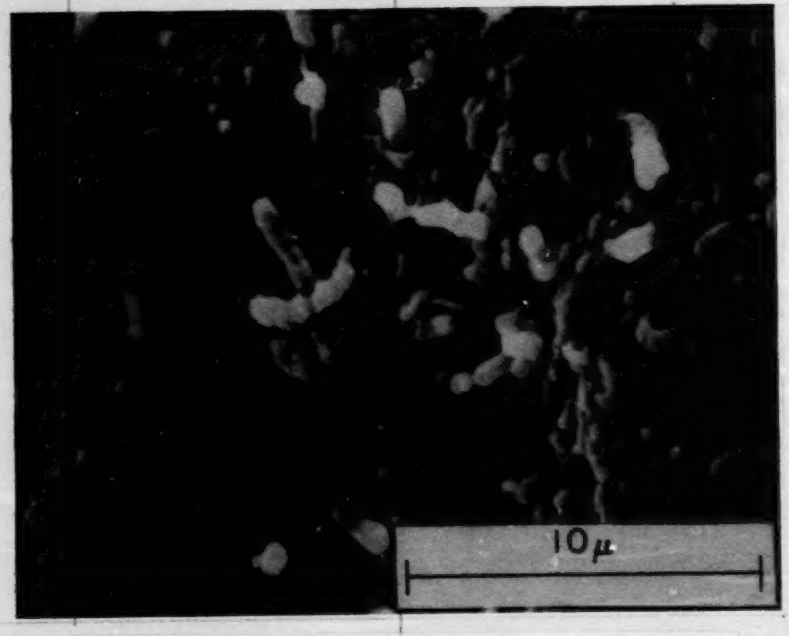

Figure 40. Run 1, top of column T2 (x5150).

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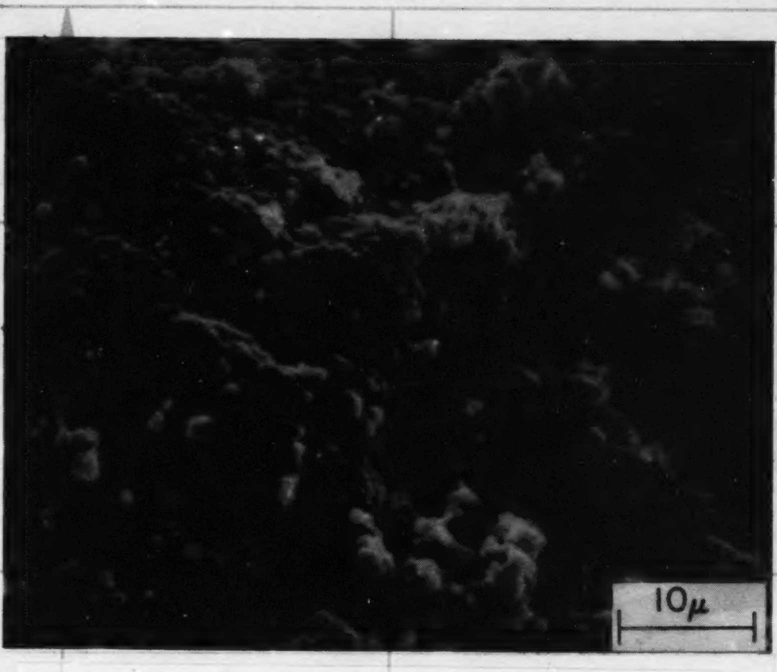

Figure 41. Run 1, bottom of column T4 (x2000).

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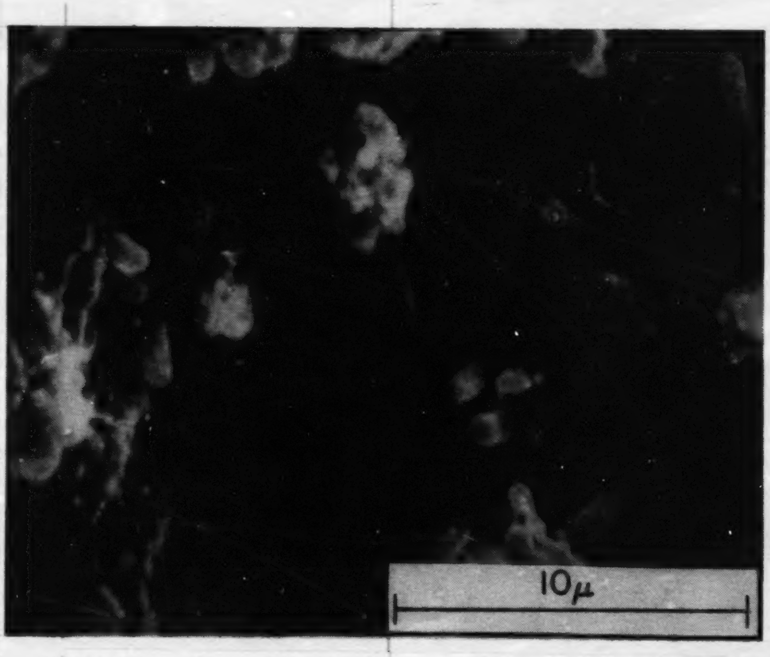

Figure 42. Run 1, top of column T4 (x5200).

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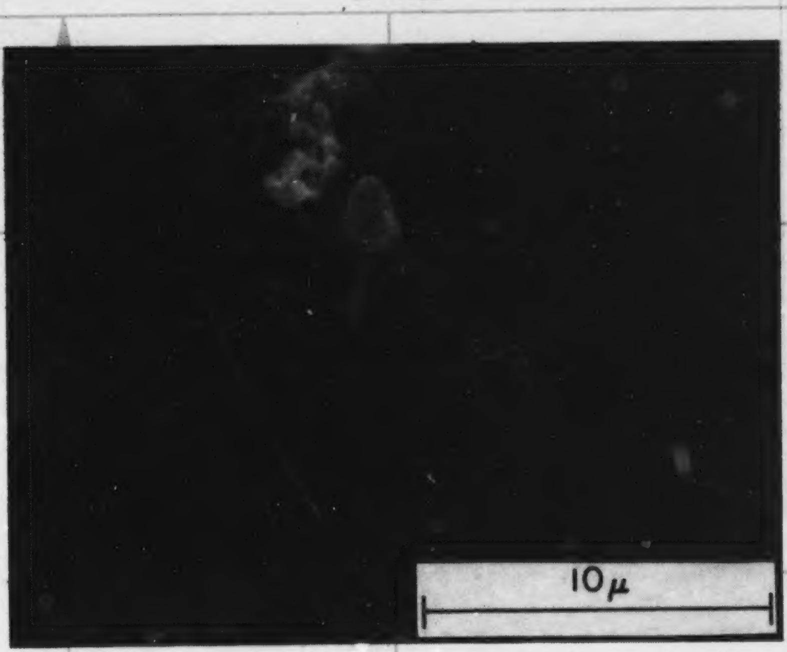

Figure 43. Run 2, bottom of column T2 (x5000).

9-1/8"

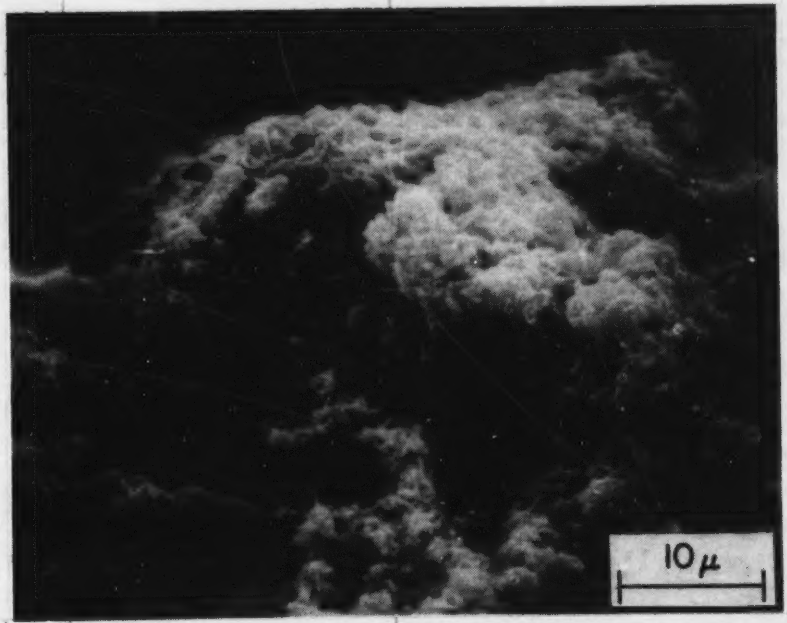

Figure 44. Run 2, bottom of column T2 (x2120).

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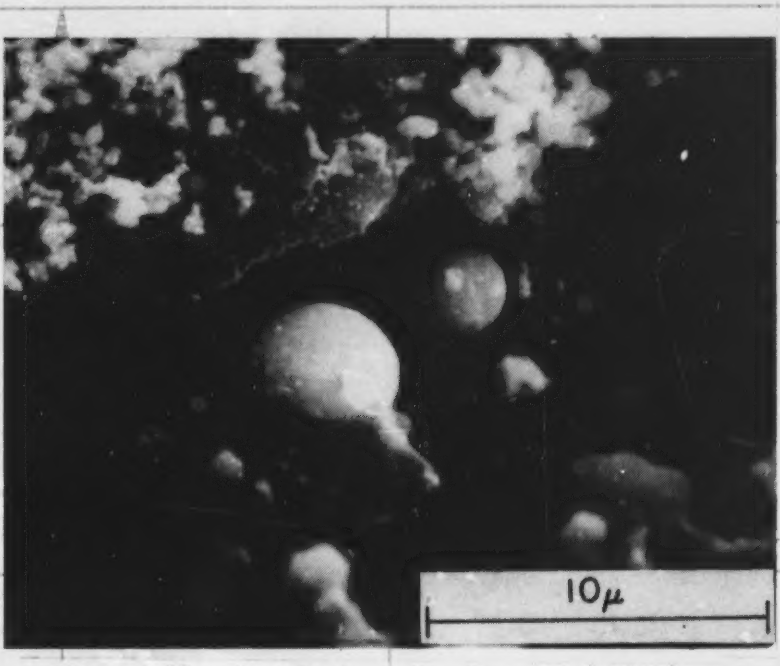

Figure 45. Run 2, top of column T4 (x5200).

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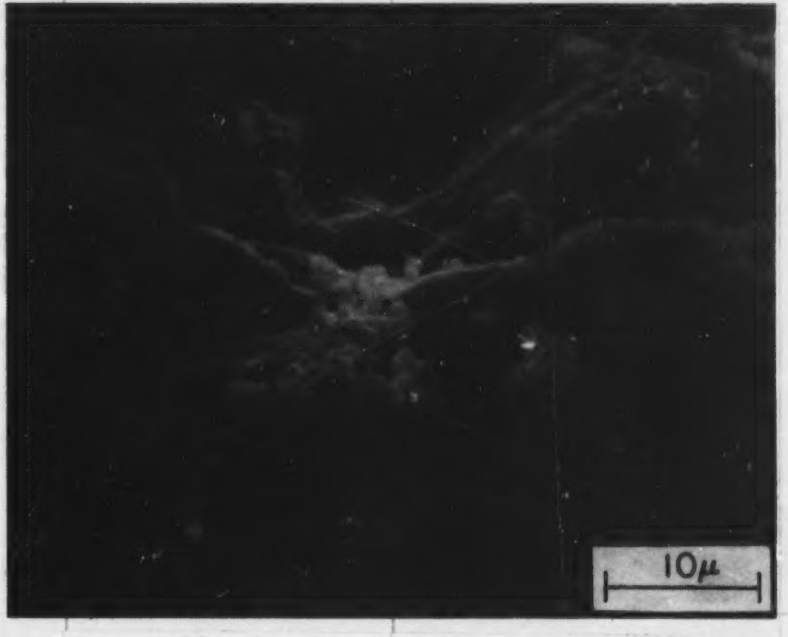

Figure 46. Run 2, top of column T3 (x2240).

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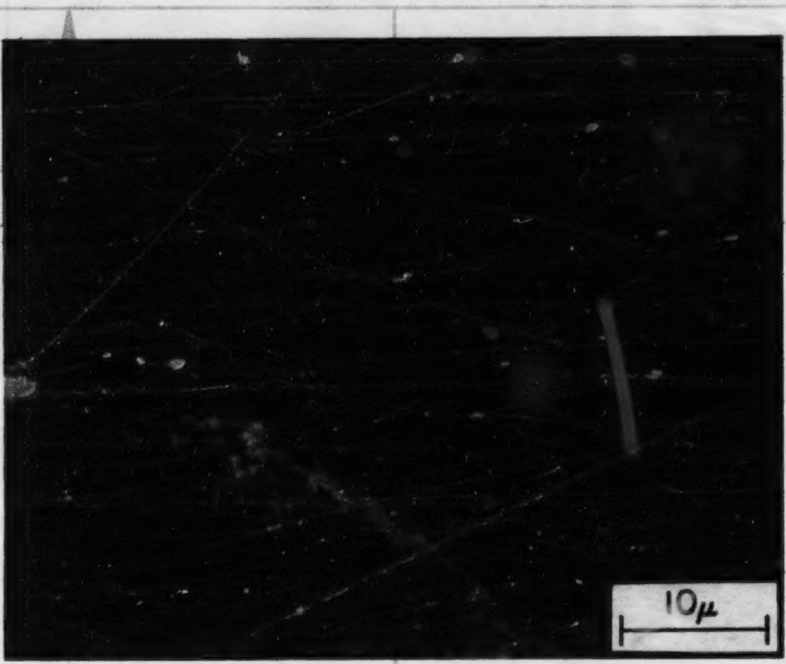

Figure 47. Run 2, bottom of column T4 (x2160).

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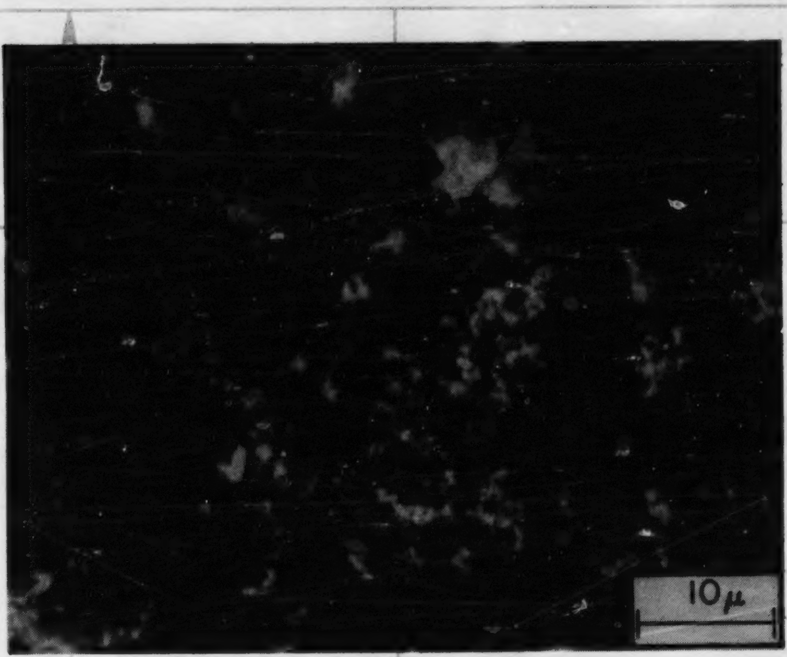

Figure 48. Run 3, blank carbon (x2000).

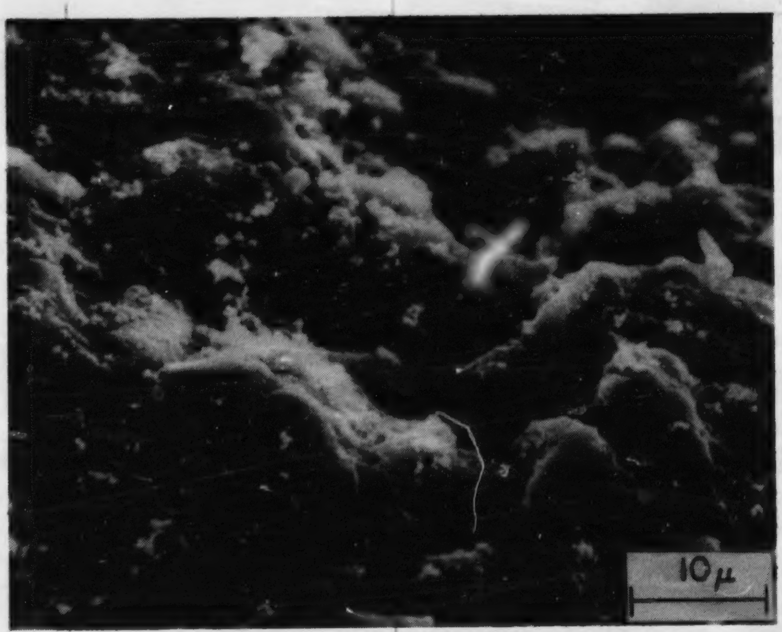

Figure 49. Run 3, top of column T2 (x2000).

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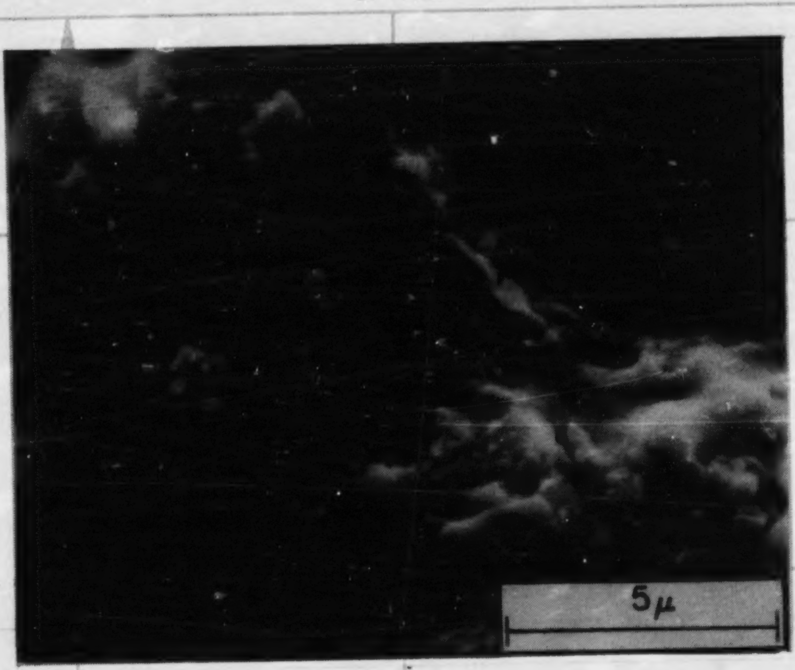

Figure 50. Run 3, bottom of column T2 (x10,000).

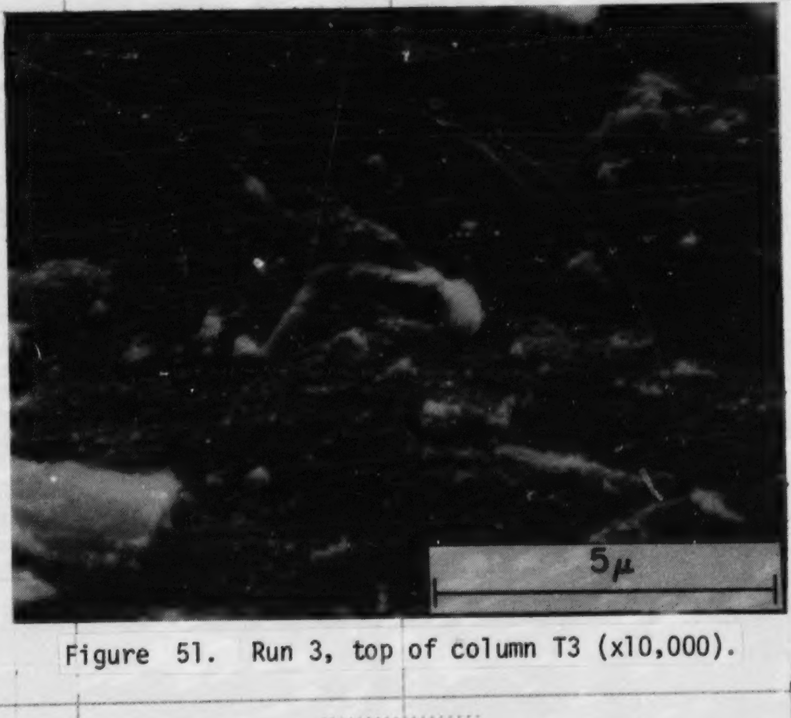

Figure 51. Run 3, top of column T3 (x10,000).

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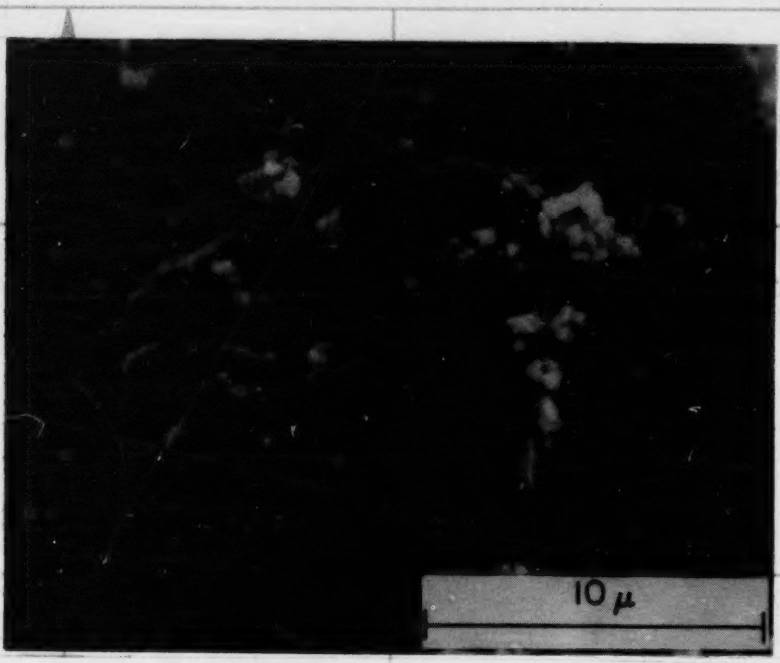

Figure 52. Run 3, bottom of column T3 (x5,000).

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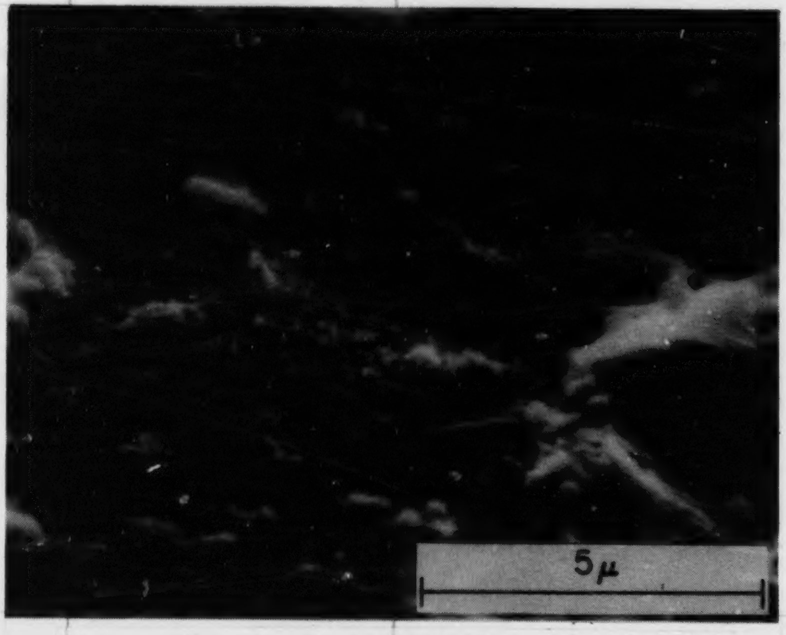

Figure 53. Run 3, top of column T4 (x10,000).

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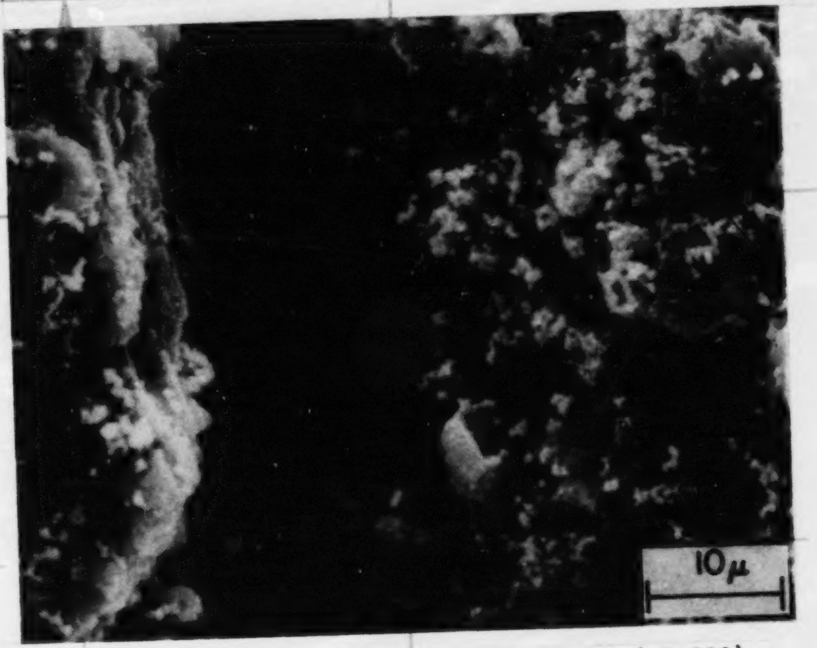

Figure 54. Run 3, bottom of column T4 (x2,000).

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Influent and Control Column Comparison

Student and pairwise t-tests comparing the influent to the control column effluent of experiment 1 and 2 (Tables 42, 43) both show a significant decrease in free chlorine. Experiment 3 (Table 44), however, shows that only the pairwise t-test has a significant decrease in free chlorine. Even with this decrease in free chlorine there was no significant difference in any of the bacterial parameters for experiments 1 and 2. In experiment 3, the student t-test for log[m-SPC] was significantly higher in the control column than in the influent, but the pairwise t-test showed the same comparison to be insignificant. This would imply that even though free chlorine values are lower in the control column no other alteration to the water's character is seen.

Hypotheses Tested

Four formal hypotheses were developed to test against the data base. They are as follows:

1. Endotoxin levels provide a good estimate of indicator organisms in GAC effluent.
2. GAC has an effect on physio-chemical and microbiological water quality parameters.
3. m-SPC is a good indicator of SPC.
4. The change in microbiological water quality parameters induced by GAC treatment is a function of the process design parameters.

Hypothesis 1. Endotoxin levels provide a good estimate of indicator organisms in GAC effluent--

Free and total endotoxin data correlated with each separate log transformed bacterial parameter for all experiments and specific data combinations do not provide a good estimate of indicator organisms in the GAC columns effluent. There were only three occurrences of significant correlations of both types of endotoxins with bacterial parameters and they appeared in experiment 3, station T4 (Table 35) and experiment 2, station T4 (Table 36). The few other significant correlations are found sporadically in the influent stream and the control column effluent.

Hypothesis 2. GAC has an effect on physico-chemical and microbiological water quality parameters--

Generally, both the student t-test and the pairwise t-test of the influent water compared to the effluent water of the GAC columns exhibited a significant change, common to all three experiments, in the levels of free chlorine, total chlorine, and m-SPC values (Tables 45-53). Using the same tests, these parameters also prove to be significantly different in the control column effluent compared to the GAC columns effluent for all three experiments (Tables 54-62). The trends for these three parameters display a decrease of both free and total chlorine across the GAC columns and an increase in m-SPC values.

More specifically, the student t-test for experiments 1 and 2 directly follow the above results. However, the third experiment shows that SPC is

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TABLE 42. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS TI-T1

Variable	Student			Pairwise		
	Mean	Sign.	N	Mean	Sign.	N
pH	6.6673^a	0.8952	11	6.6673^a	0.6681	11
	6.6783^b		11	6.6782^b		
Temp	3.8400^a	1.0000	15	3.8400^a	-	15
	3.8400^b		15	3.8400^b		
CLF	0.38214^a	0.0327*	14	0.38214^a	0.0012*	14
	0.26071^b		14	0.26071^b		
CLT	0.50571^a	0.5283	14	0.50571^a	0.2324	14
	0.47000^b		14	0.47000^b		
Turb	0.30692^a	0.9493	13	0.30692^a	0.8980	13
	0.30308^b		13	0.30308^b		
DO	13.000^a	0.6339	13	13.000^a	0.0036*	13
	12.862^b		13	12.862^b		
LOG[SPC]	0.02130^a	0.5902	8	0.10472^a	0.8473	6
	0.17456^b		9	0.18258^b		
LOG[m-SPC]	-1.4413^a	0.2201	6	-1.6709^a	0.0953	4
	-0.8686^b		5	-1.1838^b		
LOG[AF]	-0.40905^a	0.8911	12	-0.40905^a	0.4058	12
	-0.38152^b		13	-0.32998^b		
Total Endotoxins	1.2252^a	0.3543	6	1.2252^a	0.0985	6
	0.8355^b		6	0.8355^b		
Free Endotoxins	0.88160^a	0.9748	5	1.0670^a	0.9095	4
	0.89160^b		5	1.0382^b		

---

[a] TI - Influent

[b] T1

* Significance $\leq$ 0.05

TABLE 43. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS TI-T1

Variable	Student Mean	Student Sign.	Student N	Pairwise Mean	Pairwise Sign.	Pairwise N
pH	6.6314[a]	0.6546	14	6.6314[a]	0.4777	14
	6.6529[b]		14	6.6529[b]		
Temp	17.200[a]	1.0000	14	17.200[a]	-	14
	17.200[b]		14	17.200[b]		
CLF	0.27429[a]	0.0182*	14	0.27429[a]	0.0011*	14
	0.17929[b]		14	0.17929[b]		
CLT	0.42143[a]	0.7677	14	0.42143[a]	0.0152*	14
	0.40929[b]		14	0.40929[b]		
Turb	0.13000[a]	0.2217	13	0.13000[a]	0.2106	13
	0.10846[b]		13	0.10846[b]		
DO	8.4333[a]	1.0000	12	8.4333[a]	1.0000	12
	8.4333[b]		12	8.4333[b]		
LOG[SPC]	0.17341[a]	0.9525	7	0.3367[a]	0.6404	4
	0.15555[b]		6	0.47408[b]		
LOG[m-SPC]	-2.0837[a]	0.7287	8	-2.0210[a]	0.3789	7
	-2.1887[b]		12	-2.2344[b]		
LOG[AF]	-0.30826[a]	0.6402	8	-0.30826[a]	0.7981	8
	-0.36632[b]		9	-0.34043[b]		
Total Endotoxins	0.95000[a]	0.7942	9	0.95000[a]	0.2334	9
	0.89111[b]		9	0.89111[b]		
Free Endotoxins	0.70778[a]	0.8643	9	0.70778[a]	0.3674	9
	0.67778[b]		9	0.67778[b]		

---

[a] TI - Influent
[b] T1
* Significance ≤ 0.05

TABLE 44. STUDENT AND PAIRWISE t-TESTS COMPARING TI TO T1 FOR EXPERIMENT #3

Variable	Student Mean	Student Significance	Student N	Pairwise Mean	Pairwise Significance	Pairwise N
pH	6.5437[a] 6.5775[b]	0.6700	8 8	6.5437[a] 6.5775[b]	0.0099	8
Temp	19.225[a] 19.237[b]	0.9965	8 8	19.225[a] 19.237[b]	0.3506	8
CLF	0.54125[a] 0.40625[b]	0.4068	8 8	0.54125[a] 0.40625[b]	0.0011*	8
CLT	0.69250[a] 0.67250[b]	0.9007	8 8	0.69250[a] 0.67250[b]	0.0185*	8
Turb	0.09333[a] 0.10667[b]	0.4510	6 6	0.093333[a] 0.10667[b]	0.4746	6
DO	7.0714[a] 7.0571[b]	0.9829	7 7	7.0714[a] 7.0571[b]	0.7358	7
LOG[SPC]	-0.41892[a] -0.26366[b]	0.3641	5 6	-0.37983[a] -0.45842[b]	0.2007	3
LOG[m-SPC]	-2.0808[a] -1.1262[b]	0.0381*	4 7	-2.0808[a] -0.86577[b]	0.1259	4
LOG[acid-fast]	-0.61734[a] -0.73813[b]	0.6895	3 2	-0.48794[a] -0.73813[b]	0.5000	2
Total Endotoxins	0.61167[a] 0.50920[b]	0.6471	6 5	0.58000[a] 0.50920[b]	0.3200	5
Free Endotoxins	0.73100[a] 0.58083[b]	0.6574	7 6	0.72450[a] 0.58083[b]	0.0219*	6

---

[a] TI - Influent

[b] T1

* Significance at 0.05 level

TABLE 45. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS TI-T2

Variable	Student Mean	Student Sign.	Student N	Pairwise Mean	Pairwise Sign.	Pairwise N
pH	6.6673[a] 6.6873[b]	0.7875	11 11	6.6673[a] 6.6873[b]	0.5768	11
Temp	3.8400[a] 3.8400[b]	1.0000	15 15	3.8400[a] 3.8400[b]	-	15
CLF	0.38214[a] 0.00714[b]	0.0000*	14 14	0.38214[a] 0.00714[b]	0.0000*	14
CLT	0.50571[a] 0.11143[b]	0.0000*	14 14	0.50571[a] 0.11143[b]	0.0000*	14
Turb	0.30692[a] 0.29154[b]	0.8010	13 13	0.3069[a] 0.2915[b]		13
DO	13.000[a] 12.662[b]	0.2559	13 13	13.000[a] 12.662[b]	0.0000*	13
LOG[SPC]	0.02130[a] 0.48777[b]	0.1131	9 12	0.02130[a] 0.39741[b]	0.1654	9
LOG[m-SPC]	-1.4413[a] 2.7011[b]	0.0000*	5 8	-1.4413[a] 2.8713[b]	0.0001*	5
LOG[AF]	-0.40905[a] -0.42883[b]	0.9260	12 12	-0.4066[a] -0.4043[b]	0.9827	11
Total Endotoxins	1.2252[a] 0.9595[b]	0.5148	6 6	1.2252[a] 0.9595[b]	0.3908	6
Free Endotoxins	0.8816[a] 1.0123[b]	0.7049	6 5	0.8816[a] 1.0580[b]	0.2345	5

---

[a] TI - Influent
[b] T2
* Significance ≤ 0.05

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TABLE 46. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS TI-T3

Variable	Student			Pairwise		
	Mean	Sign.	N	Mean	Sign.	N
pH	6.6673[a] 6.8091[b]	0.2210	11 11	6.6673[a] 6.8091[b]	0.3559	11
Temp	3.8400[a] 3.8400[b]	1.0000	15 15	3.8400[a] 3.8400[b]	-	15
CLF	0.38214[a] 0.0000[b]	-	14 14	0.38214[a] 0.0000[b]	0.0000*	14
CLT	0.50571[a] 0.07500[b]	0.0000*	14 14	0.50571[a] 0.07500[b]	0.0000*	14
Turb	0.30692[a] 0.29000[b]	0.7893	13 12	0.32667[a] 0.29000[b]	0.0990	12
DO	13.000[a] 12.592[b]	0.1705	13 13	13.000[a] 12.592[b]	0.0000*	13
LOG[SPC]	0.02130[a] 1.2101[b]	0.0071*	9 10	0.27204[a] 0.67810[b]	0.4489	6
LOG[m-SPC]	-1.4413[a] 3.3903[b]	0.0000*	5 9	-1.4413[a] 3.6611[b]	0.0000*	5
LOG[AF]	-0.40905[a] -0.41813[b]	0.9623	12 10	-0.39040[a] -0.37822[b]	0.9120	9
Total Endotoxins	1.2252[a] 1.4526[b]	0.7798	6 5	1.1796[a] 1.4526[b]	0.4973	5
Free Endotoxins	0.88160[a] 1.1126[b]	0.6901	5 5	0.86225[a] 1.2522[b]	0.2977	4

---

[a] TI - Influent

[b] T3

* Significance $\le$ 0.05

TABLE 47. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS TI-T4

	Student			Pairwise		
Variable	Mean	Sign.	N	Mean	Sign.	N
pH	6.6673[a]	0.2504	11	6.6673[a]	0.3603	11
	6.8864[b]		11	6.8864[b]		
Temp	3.8400[a]	1.0000	15	3.84[a]	-	15
	3.8400[b]		15	3.84[b]		
CLF	0.38214[a]	-	14	0.38214[a]	0.0000*	14
	0.0000[b]		14	0.0000[b]		
CLT	0.50571[a]	0.0000	14	0.50571[a]	0.0000*	14
	0.01429[b]		14	0.01429[b]		
Turb	0.30692[a]	0.6507	13	0.30692[a]	0.1225	13
	0.27846[b]		13	0.27846[b]		
DO	13.000[a]	0.0916	13	13.000[a]	0.0000*	13
	12.485[b]		13	12.485[b]		
LOG[SPC]	0.02130[a]	0.1571	9	-0.13115[a]	0.1229	7
	0.4816[b]		11	0.24275[b]		
LOG[m-SPC]	-1.4413[a]	0.0000*	5	-1.4376[a]	0.0005*	4
	3.7430[b]		8	3.9795[b]		
LOG[AF]	-0.40905[a]	0.9479	12	-0.38395[a]	0.9163	10
	-0.39560[b]		10	-0.39560[b]		
Total Endotoxins	1.2252[a]	0.5023	6	1.3010[a]	0.3197	5
	1.8330[b]		5	1.8330[b]		
Free Endotoxins	0.8816[a]	0.4543	5	0.88160[a]	0.0497*	5
	1.2482[b]		6	1.3846[b]		

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[a] TI - Influent
[b] T4
*Significance ≤ 0.05

TABLE 48. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS TI-T2

	Student			Pairwise		
Variable	Mean	Sign.	N	Mean	Sign.	N
pH	6.6314[a] 6.8550[b]	0.2992	14 14	6.6314[a] 6.8550[b]	0.2571	14
Temp	17.200[a] 17.200[b]	1.0000	14 14	17.200[a] 17.200[b]	-	14
CLF	0.27429[a] 0.0000[b]	-	14 14	0.27429[a] 0.0000[b]	0.0000*	14
CLT	0.42143[a] 0.04643[b]	0.0000*	14 14	0.42143[a] 0.04643[b]	0.0000*	14
Turb	0.13000[a] 0.11385[b]	0.3801	13 13	0.13000[a] 0.11385[b]	0.2073	13
DO	8.4333[a] 7.6917[b]	0.2854	12 12	8.4333[a] 7.6917[b]	0.2539	12
LOG[SPC]	0.17341[a] -0.07790[b]	0.3585	7 9	0.17341[a] -0.00653[b]	0.5737	7
LOG[m-SPC]	-2.0837[a] -1.0007[b]	0.0114*	8 12	-2.1698[a] -0.75822[b]	0.0243*	7
LOG[AF]	-0.30826[a] -0.27063[b]	0.7623	8 9	-0.30826[a] -0.30263[b]	0.9623	8
Total Endotoxins	0.95000[a] 1.0675[b]	0.6304	9 8	0.8700[a] 1.0675[b]	0.2841	8
Free Endotoxins	0.70778[a] 1.0267[b]	0.1878	9 9	0.70778[a] 1.0267[b]	0.0081*	9

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[a] TI - Influent
[b] T2
*Significance $\leq$ 0.05

TABLE 49. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS TI-T3

	Student			Pairwise		
Variable	Mean	Sign.	N	Mean	Sign.	N
pH	6.6314[a]	0.3166	14	6.6314[a]	0.2756	14
	6.8531[b]		14	6.68571[b]		
Temp	17.200[a]	1.0000	14	17.200[a]	-	14
	17.200[b]		14	17.200[b]		
CLF	0.27429[a]	0.0000*	14	0.27429[a]	0.0000*	14
	0.00786[b]		14	0.00786[b]		
CLT	0.42143[a]	0.0000*	14	0.42143[a]	0.0000*	14
	0.06071[b]		14	0.06071[b]		
Turb	0.13000[a]	0.7766	13	0.13000[a]	0.7431	13
	0.12385[b]		13	0.12385[b]		
DO	8.4333[a]	0.2845	12	8.4333[a]	0.2287	12
	7.7250[b]		12	7.7250[b]		
LOG[SPC]	0.17341[a]	0.3225	7	0.17341[a]	0.1545	7
	0.43316[b]		12	0.55771[b]		
LOG[m-SPC]	-2.0837[a]	0.0000*	8	-2.0837[a]	0.0000*	8
	0.14606[b]		14	0.11675[b]		
LOG[AF]	-0.30826[a]	0.6916	8	-0.24125[a]	0.6644	7
	-0.26277[b]		8	-0.27817[b]		
Total Endotoxins	0.95000[a]	0.4228	9	0.95000[a]	0.0961	9
	1.1644[b]		9	1.1644[b]		
Free Endotoxins	0.70770[a]	0.4125	9	0.70770[a]	0.2750	9
	0.89444[b]		9	0.89444[b]		

---

[a] TI - Influent
[b] T3
* Significance ≤ 0.05

TABLE 50. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS TI-T4

	Student			Pairwise		
Variable	Mean	Sign.	N	Mean	Sign.	N
pH	6.6314[a]	0.3652	14	6.6314[a]	0.3115	14
	6.8057[b]		14	6.8057[b]		
Temp	17.200[a]	1.0000	14	17.200[a]	-	14
	17.200[b]		14	17.200[b]		
CLF	0.27429[a]	0.0000*	14	0.27429[a]	0.0000*	14
	0.01500[b]		14	0.01500[b]		
CLT	0.42143[a]	0.0000*	14	0.42143[a]	0.0000*	14
	0.11857[b]		14	0.11857[b]		
Turb	0.13000[a]	0.1545	13	0.13000[a]	0.1019	13
	0.10534[b]		13	0.10538[b]		
DO	8.4333[a]	0.5461	12	8.4333[a]	0.2202	12
	8.0833[b]		12	8.0833[b]		
LOG[SPC]	0.17341[a]	0.7506	7	0.17341[a]	0.4754	7
	0.08001[b]		11	0.35636[b]		
LOG[m-SPC]	-2.0837[a]	0.0369*	8	-2.3647[a]	0.0142*	6
	-1.4045[b]		9	-1.3869[b]		
LOG[AF]	-0.30826[a]	0.9727	8	-0.24125[a]	0.7385	7
	-0.30041[b]		8	-0.32380[b]		
Total Endotoxins	0.95000[a]	0.4869	9	0.95000[a]	0.1057	9
	1.1167[b]		9	1.1167[b]		
Free Endotoxins	0.70778[a]	0.4036	9	0.70778[a]	0.0105*	9
	0.88333[b]		9	0.88333[b]		

---

[a] TI - Influent
[b] T4
* Significance ≤ 0.05

TABLE 51. STUDENT AND PAIRWISE t-TESTS COMPARING TI TO T2 FOR EXPERIMENT #3

Variable	Student Mean	Student Significance	Student N	Pairwise Mean	Pairwise Significance	Pairwise N
pH	6.5437[a] 6.5062[b]	0.6875	8 8	6.5437[a] 6.5062[b]	0.5212	8
Temp	19.225[a] 19.237[b]	0.9965	8 8	19.225[a] 19.237[b]	0.3506	8
CLF	0.54125[a] 0.01375[b]	0.0002	8 8	0.54125[a] 0.01375[b]	0.0014*	8
CLT	0.69250[a] 0.08000[b]	0.0001	8 8	0.69250[a] 0.08000[b]	0.0011*	8
Turb	0.09333[a] 0.09500[b]	0.7872	6 6	0.09333[a] 0.09500	0.7711	6
DO	7.0714[a] 6.8857[b]	0.7830	7 7	7.0714[a] 6.8857[b]	0.0734	7
LOG[SPC]	-0.41892[a] 2.6989[b]	0.0000*	5 7	-0.40328[a] 2.9296[b]	0.0072*	4
LOG[m-SPC]	-2.0808[a] 2.3828[b]	0.0000*	4 6	-2.5229[a] 2.8770[b]	0.0882	2
LOG[acid-fast]	-0.61734[a] -0.82542[b]	0.4163	3 3	-0.61734[a] -0.82542[b]	0.4411	3
Total Endotoxins	0.61167[a] 0.77217[b]	0.5278	6 6	0.61167[a] 0.77217[b]	0.0060*	6
Free Endotoxins	0.73100[a] 0.79914[b]	0.8286	7 7	0.73100[a] 0.79914[b]	0.1567	7

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[a] TI - Influent
[b] T2
* Significance at 0.05 level

TABLE 52. STUDENT AND PAIRWISE t-TESTS COMPARING TI TO T3 FOR EXPERIMENT #3

Variable	Student Mean	Student Significance	N	Pairwise Mean	Pairwise Significance	N
pH	6.5437^a 6.5962^b	0.5061	8 8	6.5437^a 6.5962^b	0.0399*	8
Temp	19.225^a 19.237^b	0.9965	8 8	19.225^a 19.237^b	0.3506	8
CLF	0.54125^a 0.00875^b	0.0002*	8 8	0.54125^a 0.00875^b	0.0013*	8
CLT	0.69250^a 0.10375^b	0.0001*	8 8	0.69250^a 0.10375^b	0.0015*	8
Turb	0.09333^a 0.09167^b	0.8430	6 6	0.09333^a 0.091667^b	0.8327	6
DO	7.0714^a 6.8714^b	0.7698	7 7	7.0714^a 6.8714^b	0.1165	7
LOG[SPC]	-0.41892^a 2.1150^b	0.0001*	5 6	-0.41892^a 1.9649^b	0.0051*	5
LOG[m-SPC]	-2.0808^a 1.6528^b	0.0010*	4 3	-2.5229^a 2.6990^b	-	1
LOG[acid-fast]	-0.61734^a -0.58826^b	0.9252	3 2	-0.48794^a -0.58826^b	0.6742	2
Total Endotoxins	0.61167^a 0.64080^b	0.9069	6 5	0.58000^a 0.64080^b	0.2482	5
Free Endotoxins	0.73100^a 0.66060^b	0.8287	7 5	0.50740^a 0.66060^b	0.0466*	5

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[a] TI - Influent
[b] T3
[*] Significance at 0.05 level

TABLE 53. STUDENT AND PAIRWISE t-TESTS COMPARING TI TO T4 FOR EXPERIMENT #3

	Student			Pairwise		
Variable	Mean	Significance	N	Mean	Significance	N
pH	6.5437[a] 6.4987[b]	0.7215	8 8	6.5437[a] 6.4987[b]	0.6494	8
Temp	19.225[a] 19.237[b]	0.9965	8 8	19.225[a] 19.237[b]	0.3506	8
CLF	0.54125[a] 0.01125[b]	0.0002*	8 8	0.54125[a] 0.01125[b]	0.0018*	8
CLT	0.69250[a] 0.08875[b]	0.0001*	8 8	0.69250[a] 0.08875[b]	0.0014*	8
Turb	0.09333[a] 0.09333[b]	1.0000	6 6	0.09333[a] 0.09333[b]	1.0000	6
DO	7.0714[a] 6.9571[b]	0.8647	7 7	7.0714[a] 6.9571[b]	0.4619	7
LOG[SPC]	-0.41892[a] 2.6628[b]	0.0005*	5 5	-0.40328[a] 2.5345[b]	0.0203*	4
LOG[m-SPC]	-2.0808[a] 2.4594[b]	0.0001*	4 5	-2.5229[a] 3.6902[b]	-	1
LOG[acid-fast]	-0.61734[a] -1.0183[b]	0.2997	3 3	-0.61734[a] -1.0183[b]	0.3223	3
Total Endotoxins	0.61167[a] 0.68100[b]	0.7629	6 6	0.61167[a] 0.68100[b]	0.1306	6
Free Endotoxins	0.73160[a] 0.93229[b]	0.5992	7 7	0.73100[a] 0.93229[b]	0.0253*	7

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[a] TI - Influent

[b] T4

* Significance at 0.05 level

TABLE 54. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS T1-T2

Variable	Student			Pairwise		
	Mean	Sign.	N	Mean	Sign.	N
pH	6.6782^a 6.6873^b	0.8878	11 11	6.6782^a 6.6873^b	0.7224	11
Temp	3.8400^a 3.8400^b	1.0000	15 15	3.8400^a 3.8400^b	-	15
CLF	0.26071^a 0.00714^b	0.0000*	14 14	0.26071^a 0.00714^b	0.0001*	14
CLT	0.47000^a 0.11143^b	0.0000*	14 14	0.47000^a 0.11143^b	0.0000*	14
Turb	0.30308^a 0.29154^b	0.8358	13 13	0.30308^a 0.29154^b	0.5593*	13
DO	12.862^a 12.662^b	0.4742	13 13	12.862^a 12.662^b	0.0003*	13
LOG[SPC]	0.17456^a 0.48777^b	0.2186	8 12	0.17456^a 0.59171^b	0.0989	8
LOG[m-SPC]	-0.8686^a 2.7011^b	0.0000*	6 8	-0.86857^a 2.7314^b	0.0001*	6
LOG[AF]	-0.38152^a -0.42883^b	0.8063	13 12	-0.37352^a -0.42883^b	0.7204	12
Total Endotoxins	0.83550^a 0.95950^b	0.6835	6 6	0.83550^a 0.95950^b	0.5661	6
Free Endotoxins	0.89160^a 1.0123^b	0.6796	5 6	0.89160^a 1.1048^b		5

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[a] T1
[b] T2
[*] Significance $\leq$ 0.05

TABLE 55. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS T1-T3

	Student			Pairwise		
Variables	Mean	Sign.	N	Mean	Sign.	N
pH	6.6782[a] 6.8091[b]	0.2323	11 11	6.6782[a] 6.8091[b]	0.3294	11
Temp	3.8400[a] 3.8400[b]	1.0000	15 15	3.8400[a] 3.8400[b]	-	15
CLF	0.26071[a] 0.0000[b]	-	14 14	0.26071[a] 0.0000[b]	0.0001*	14
CLT	0.47000[a] 0.07500[b]	0.0000*	14 14	0.47000[a] 0.07500[b]	0.0000*	14
Turb	0.30308[a] 0.29000[b]	0.8206	13 12	0.30543[a] 0.29000[b]	0.2993	12
DO	12.862[a] 12.592[b]	0.3333	13 13	12.862[a] 12.592[b]	0.0004	13
LOG[SPC]	0.17456[a] 1.2101[b]	0.0127*	8 10	0.26829[a] 1.2526[b]	0.0097*	7
LOG[m-SPC]	-0.86857[a] 3.3903[b]	0.0000*	6 9	-0.8686[a] 3.4515[b]	0.0001*	6
LOG[AF]	-0.38152[a] -0.41813[b]	0.8282	13 10	-0.3260[a] -0.4181[b]	0.2982	10
Total Endotoxins	0.83550[a] 1.4526[b]	0.4230	6 5	0.85440[a] 1.4526[b]	0.3280	5
Free Endotoxins	0.89160[a] 1.1126[b]	0.6836	5 5	0.84225[a] 1.3107[b]	0.4410	4

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[a] T1
[b] T3
*Significance ≤ 0.05

TABLE 56. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS T1-T4

Variable	Student Mean	Student Sign.	Student N	Pairwise Mean	Pairwise Sign.	Pairwise N
pH	6.6782[a] 6.8864[b]	0.2649	11 11	6.6782[a] 6.8864[b]	0.3438	11
Temp	3.8400[a] 3.8400[b]	1.0000	15 15	3.8400[a] 3.8400[b]	-	15
CLF	0.26071[a] 0.00000[b]	-	14 14	0.26071[a] 0.00000[b]	0.0001*	14
CLT	0.47000[a] 0.01429[b]	0.0000*	14 14	0.47000[a] 0.01429[b]	0.0000*	14
Turb	0.30308[a] 0.27846[b]	0.6692	13 13	0.30308[a] 0.27846[b]	0.2431	13
DO	12.862[a] 12.485[b]	0.1873	13 13	12.862[a] 12.485[b]	0.0001*	13
LOG[SPC]	0.17456[a] 0.48164[b]	0.2880	8 11	0.22528[a] 0.44686[b]	0.4887	7
LOG[m-SPC]	-0.8686[a] 3.7430[b]	0.0000*	6 8	-0.84229[a] 3.8278[b]	0.0006*	5
LOG[AF]	-0.38152[a] -0.3956[b]	0.9388	13 10	-0.34076[a] -0.39560[b]	0.3875	10
Total Endotoxins	0.83550[a] 1.8330[b]	0.2552	6 5	0.89680[a] 1.8330[b]	0.2282	5
Free Endotoxins	0.89160[a] 1.2482[b]	0.4322	5 6	0.89160[a] 1.4218[b]	0.1669	5

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[a] T1
[b] T4
* Significance ≤ 0.05

TABLE 57. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS T1-T2

Variable	Student Mean	Student Sign.	Student N	Pairwise Mean	Pairwise Sign.	Pairwise N
pH	6.6529[a] 6.8550[b]	0.3488	14 14	6.6529[a] 6.8550[b]	0.2876	14
Temp	17.200[a] 17.200[b]	1.0000	14 14	17.200[a] 17.200[b]	-	14
CLF	0.17929[a] 0.0000[b]	-	14 14	0.17929[a] 0.0000[b]	0.0000*	14
CLT	0.40929[a] 0.04643[b]	0.0000*	14 14	0.40929[a] 0.04643[b]	0.0000*	14
Turb	0.10846[a] 0.11385[b]	0.6136	13 13	0.10846[a] 0.11385[b]	0.5762	13
DO	8.4333[a] 7.6917[b]	0.2765	12 12	8.4333[a] 7.6917[b]	0.2402	12
LOG[SPC]	0.15555[a] -0.07790[b]	0.4119	6 9	0.47408[a] 0.22833[b]	0.5843	4
LOG[m-SPC]	-2.1887[a] -1.0007[b]	0.0011*	12 12	-2.2530[a] -1.0246[b]	0.0030*	11
LOG[AF]	-0.36632[a] -0.27063[b]	0.2947	9 9	-0.36632[a] -0.27063[b]	0.3664	9
Total Endotoxins	0.89111[a] 1.0675[b]	0.4736	9 8	0.78500[a] 1.0675[b]	0.1025	8
Free Endotoxins	0.67778[a] 1.0267[b]	0.1360	9 9	0.67778[a] 1.0267[b]	0.0087*	9

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[a] T1
[b] T2
* Significance ≤ 0.05

TABLE 58. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS T1-T3

	Student			Pairwise		
Variable	Mean	Sign.	N	Mean	Sign.	N
pH	6.6529^a	0.3655	14	6.6529^a	0.3091	14
	6.8571^b		14	6.8571^b		
Temp	17.200^a	1.0000	14	17.200^a	-	14
	17.200^b		14	17.200^b		
CLF	0.17929^a	0.0000^*	14	0.17929^a	0.0000^*	14
	0.00786^b		14	0.00786^b		
CLT	0.40929^a	0.0000^*	14	0.40929^a	0.0000^*	14
	0.06071^b		14	0.06071^b		
Turb	0.10846^a	0.3346	13	0.10846^a	0.2915	13
	0.12385^b		13	0.12385^b		
DO	8.4333^a	0.2748	12	8.4333^a	0.2142	12
	7.7250^b		12	7.7250^b		
LOG[SPC]	0.15555^a	0.3143	6	0.15555^a	0.1510	6
	0.43316^b		12	0.42113^b		
LOG[m-SPC]	-2.1887^a	0.0000^*	12	-2.1887^a	0.0000^*	12
	0.14606^b		14	0.12083^b		
LOG[AF]	-0.36632^a	0.1652	9	-0.34675^a	0.3426	8
	-0.26277^b		8	-0.26277^b		
Total Endotoxins	0.89111^a	0.3111	9	0.89111^a	0.0161^*	9
	1.1644^b		9	1.1644^b		
Free Endotoxins	0.67778^a	0.3217	9	0.67778^a	0.0695	9
	0.89444^b		9	0.89444^b		

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[a] T1
[b] T3
[*] Significance ≤ 0.05

TABLE 59. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS T1-T4

Variable	Student			Pairwise		
	Mean	Sign.	N	Mean	Sign.	N
pH	6.6529^a 6.8057^b	0.4285	14 14	6.6529^a 6.8057^b	0.3563	14
Temp	17.200^a 17.200^b	1.0000	14 14	17.200^a 17.200^b	-	14
CLF	0.17929^a 0.015000^b	0.0000*	14 14	0.17929^a 0.01500^b	0.0000*	14
CLT	0.40929^a 0.11857^b	0.0000*	14 14	0.40929^a 0.11857^b		14
Turb	0.10846^a 0.10538^b	0.7054	13 13	0.10846^a 0.10538^b		13
DO	8.4333^a 8.0833^b		12 12	8.4333^a 8.08333^b		12
LOG[SPC]	0.15555^a 0.08000^b	0.8073	6 11	0.28296^a 0.43935^b	0.5377	5
LOG[m-SPC]	-2.1887^a -1.4045^b	0.0055*	12 9	-2.4083^a -1.4531^b	0.0070*	7
LOG[AF]	-0.36632^a -0.30041^b	0.7420	9 8	-0.34675^a -0.30041^b	0.8348	8
Total Endotoxins	0.89111^a 1.1167^b	0.3511	9 9	0.89111^a 1.1167^b	0.0914	9
Free Endotoxins	0.67778^a 0.88333^b	0.3046	9 9	0.67778^a 0.88333^b	0.0097*	9

---

[a] T1
[b] T4
* Significance $\leq$ 0.05

TABLE 60. STUDENT AND PAIRWISE t-TESTS COMPARING T1 TO T2 FOR EXPERIMENT #3

	Student			Pairwise		
Variable	Mean	Significance	N	Mean	Significance	N
pH	6.5775[a] 6.5062[b]	0.4431	8 8	6.5775[a] 6.5062[b]	0.2012	8
Temp	19.237[a] 19.237[b]	1.0000	8 8	19.237[a] 19.237[b]	-	8
CLF	0.40625[a] 0.01375[b]	0.0047*	8 8	0.40625[a] 0.01375[b]	0.0107*	8
CLT	0.67250[a] 0.08000[b]	0.0001*	8 8	0.67250[a] 0.08000[b]	0.0011*	8
Turb	0.10667[a] 0.09500[b]	0.5265	6 6	0.10667[a] 0.095000[b]	0.4819	6
DO	7.0571[a] 6.8857[b]	0.7977	7 7	7.0571[a] 6.8857[b]	0.0167*	7
LOG[SPC]	-0.26366[a] 2.6989[b]	0.0000*	6 7	-0.22010[a] 2.3885[b]	0.0017*	5
LOG[m-SPC]	-1.1262[a] 2.3828[b]	0.0000*	7 6	-1.0186[a] 2.1901[b]	0.0012*	5
LOG[acid-fast]	-0.73813[a] -0.82542[b]	0.5196	2 3	-0.73813[a] -0.88864[b]	0.2847	2
Total Endotoxins	0.50920[a] 0.77217[b]	0.2948	5 6	0.50920[a] 0.71660[b]	0.0753	5
Free Endotoxins	0.58083[a] 0.79914[b]	0.4909	6 7	0.58083[a] 0.78733[b]	0.0033*	6

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[a] T1

[b] T2

* Significance at 0.05 level

TABLE 61. STUDENT AND PAIRWISE t-TESTS COMPARING T1 TO T3 FOR EXPERIMENT #3

Variable	Mean	Student Significance	N	Mean	Pairwise Significance	N
pH	6.5775^a 6.5962^b	0.8080	8 8	6.5775^a 6.5962^b	0.3979	8
Temp	19.237^a 19.237^b	1.0000	8 8	19.237^a 19.237^b	-	8
CLF	0.40625^a 0.00875^b	0.0043*	8 8	0.40625^a 0.00875^b	0.0100*	8
CLT	0.67250^a 0.10375^b	0.0002*	8 8	0.67250^a 0.10375^b	0.0016*	8
Turb	0.10667^a 0.09167^b	0.4395	6 6	0.10667^a 0.09167^b	0.2480	6
DO	7.0571^a 6.8714^b	0.7841	7 7	7.0571^a 6.8714^b	0.0523	7
LOG[SPC]	-0.26366^a 2.1150^b	0.0001*	6 6	-0.15475^a 1.9277^b	0.0621	4
LOG[m-SPC]	-1.1262^a 1.6528^b	0.0006*	7 3	-1.0278^a 1.9608^b	0.0143*	2
LOG[acid-fast]	-0.73813^a -0.58826^b	0.3300	2 2	-0.73813^a -0.58826^b	0.2836	2
Total Endotoxins	0.50920^a 0.64080^b	0.5734	5 5	0.50920^a 0.64080^b	0.1064	5
Free Endotoxins	0.58083^a 0.66060^b	0.7995	6 5	0.39400^a 0.66060^b	0.0033*	5

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^{a}T1
^{b}T3
*Significance at 0.05 level

TABLE 62. STUDENT AND PAIRWISE t-TESTS COMPARING T1 TO T4 FOR EXPERIMENT #3

	Student			Pairwise		
Variable	Mean	Significance	N	Mean	Significance	N
pH	6.5775[a]	0.5323	8	6.5775[a]	0.4109	8
	6.4987[b]		8	6.4987[b]		
Temp	12.237[a]	1.0000	8	19.237[a]	-	8
	12.237[b]		8	19.237[b]		
CLF	0.40625[a]	0.0046*	8	0.40625[a]	0.0128*	8
	0.01125[b]		8	0.01125[b]		
CLT	0.67250[a]	0.0001*	8	0.67250[a]	0.0014*	8
	0.08875[b]		8	0.88750[b]		
Turb	0.10667[a]	0.4917	6	0.10667[a]	0.3548	6
	0.09333[b]		6	0.09333[b]		
DO	7.0571[a]	0.8805	7	7.0571[a]	0.4420	7
	6.9571[b]		7	6.9571[b]		
LOG[SPC]	-0.26366[a]	0.0003*	6	-0.45842[a]	0.1231	3
	2.6628[b]		5	2.4272[b]		
LOG[m-SPC]	-1.1262[a]	0.0000*	7	-1.1942[a]	0.0023*	4
	2.4594[b]		5	2.2593[b]		
LOG[acid-fast]	-0.73813[a]	0.4701	2	-0.73813[a]	0.8789	2
	-1.0183[b]		3	-0.78674[b]		
Total Endotoxins	0.50920[a]	0.4311	5	0.50920[a]	0.0768	5
	0.68100[b]		6	0.64220[b]		
Free Endotoxins	0.58083[a]	0.3776	6	0.58083[a]	0.0277*	6
	0.93229[b]		7	0.94183[b]		

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[a] T1
[b] T4
* Significance at 0.05 level

significantly less in both the control column and in the influent water compared to the GAC columns effluent, and this tendency is also observed in the pairwise t-test for experiment 3.

Moreover, the pairwise t-test uncovered other parameters that were significantly different than the three common parameters mentioned above. In experiment 2 and 3 free endotoxin is significantly less and in experiment 1 dissolved oxygen is significantly greater in both the control column effluent and the influent compared to the GAC columns effluent.

Hypothesis 3. m-SPC is a good indicator of SPC--
Correlation coefficients and significance values of log[SPC] versus log[m-SPC] for all experiments and for specific combinations of the experimental data (Tables 33-37) revealed that m-SPC is not a good estimator of SPC. There do not appear to be any observable trends in the coefficients except possibly in the third experiment. The correlation coefficients derived from the third experiment's data seemed to indicate a high, positive correlation, but only in the GAC columns effluent.

One reason for this conclusion and its difference from results of the field study may be that there was a considerable difference in the influent SPC and m-SPC values between Troy (Tables 63-65) and Manchester (Tables 7-8). Troy generally had very low influent bacterial densities while Manchester had, relative to Troy, very high bacterial densities. This may indicate that in the presence of low microbial densities, the relationship between SPC and m-SPC becomes more tenuous. This, however, may be due to the poorer precision of the SPC technique at lower densities.

Hypothesis 4. The change in microbiological water quality parameters induced by GAC treatment is a function of the process design parameters--
Process design parameters may have some influence on the microbial water quality variables. The following tendencies were observed from the pairwise t-test and the student t-test between each GAC column effluent of experiment 1 (Tables 66-68) and experiment 2 (Tables 69-71). Both experiments showed that there was a significant increase in m-SPC values for a step increase in empty bed contact time (EBCT) from 2.5 to 5 minutes, and a significant decrease in SPC values for a step change in EBCT from 10 to 5 minutes.

Experiment 1 also indicated that m-SPC levels increased for both a step increase in EBCT from 2.5 to 10 minutes and from 5 to 10 minutes. However, experiment 2 displayed a decrease in m-SPC values with a step increase in EBCT from 5 to 10 minutes. Since in experiment 1 the height of the carbon was the manipulated variable, but in experiment 2 the velocity through the carbon was the manipulated variable, bed depth or velocity changes that tend to increase the EBCT appeared to increase the SPC and m-SPC in the GAC columns effluent; however, this effect is opposed by a tendency for decreased velocity which decreases EBCT to decrease m-SPC counts.

There were no significant differences in the microbial water parameters between the GAC columns for experiment 3 (Tables 72-74). This result may

TABLE 63. MEANS AND STANDARD ERROR FROM TROY, EXPERIMENT #1

Parameter	TI	T1	Station T2	T3	T4
pH	6.6673 (0.0622)	6.6782 (0.05066)	6.6873 (0.03852)	6.8091 (0.09342)	6.8864 (0.1743)
Temp (^oC)	3.8400 (0.2821)	3.8400 (0.2821)	3.8400 (0.2821)	3.8400 (0.2821)	3.8400 (0.2821)
CLF (mg/l)	0.38214 (0.02939)	0.26071 (0.04509)	0.00714 (0.00714)	§ -	§ -
CLT (mg/l)	0.50571 (0.03406)	0.47000 (0.04429)	0.11143 (0.01848)	0.07500 (0.01898)	0.01429 (0.0097)
Turb (NTU)	0.30692 (0.04577)	0.30308 (0.03849)	0.29154 (0.03937)	0.29000 (0.04225)	0.27846 (0.04192)
DO (mg/l)	13.000 (0.2136)	12.862 (0.19167	12.662 (0.1973)	12.592 (0.1939)	12.485 (0.2009)
LOG[SPC] (CFU/ml)	0.02130 (0.2269)	0.17456 (0.1475)	0.4877 (0.1740)	1.2101 (0.3066)	0.48164 (0.2122)
LOG[m-SPC] (CFU/ml)	-1.4413 (0.2816)	-0.86857 (0.3188)	2.7011 (0.1303)	3.3903 (0.1574)	3.7430 (0.1503)
LOG[AF] (CFU/100ml)	-0.40905 (0.1545)	-0.38152 (0.1272)	-0.42883 (0.1428)	-0.41813 (0.09231)	-0.39560 (0.1231)
LOG[TCOLI] (CFU/100ml)	§ -	§ -	§ -	§ -	§ -
Total Endotoxins (μg/l)	1.2252 (0.3380)	0.83550 (0.2161)	0.95950 (0.2012)	1.4526 (0.7703)	1.8330 (0.8700)
Free Endotoxins (μg/l)	0.88160 (0.2580)	0.89160 (0.1663)	1.0123 (0.2169)	1.1126 (0.4955)	1.2482 (0.3680)

(   ) Standard errors of observations
§N = 0
TI - Influent

TABLE 64. MEANS AND STANDARD ERROR FROM TROY, EXPERIMENT #2

Parameter	Station TI	T1	T2	T3	T4
pH	6.6314 (0.03075)	6.6529 (0.0360)	6.8550 (0.2088)	6.8571 (0.2189)	6.8057 (0.1866)
Temp (^oC)	17.200 (1.0361)	17.200 (1.0361)	17.200 (1.0361)	17.200 (1.0361)	17.200 (1.0361)
CLF (mg/l)	2.7429 (0.02694)	0.17929 (0.02634)	§ -	0.007857 (0.005364)	0.01500 (0.006692)
CLT (mg/l)	0.42143 (0.02931)	0.40929 (0.02819)	0.04643 (0.01189)	0.060714 (0.01462)	0.11857 (0.01078)
Turb (NTU)	0.1300 (0.01597)	0.10846 (0.006289)	0.11385 (0.00844)	0.12385 (0.01430)	0.10538 (0.005015)
DO (mg/l)	8.4333 (0.4385)	8.4333 (0.4187)	7.6917 (0.5162)	7.7250 (0.4739)	8.0833 (0.3655)
LOG[SPC] (CFU/ml)	0.17341 (0.2001)	0.15555 (0.2136)	-0.07790 (0.1740)	0.43316 (0.1557)	0.080008 (0.1913)
LOG[m-SPC] (CFU/ml)	-2.0837 (0.2520)	-2.1887 (0.1766)	-1.0007 (0.2639)	0.14606 (0.1496)	-1.4045 (0.1678)
LOG[AF] (CFU/100ml)	-0.30826 (0.1089)	-0.36632 (0.06206)	-0.27063 (0.06287)	-0.26277 (0.02762)	-0.30041 (0.1971)
LOG[TCOLI] (CFU/100ml)	§ -	§ -	§ -	§ -	§ -
Total Endotoxins (μg/l)	0.95000 (0.1565)	0.89111 (0.1575)	1.0675 (0.1829)	1.1644 (0.2085)	1.1167 (0.1742)
Free Endotoxins (μg/l)	0.70778 (0.1306)	0.67778 (0.1129)	1.0267 (0.1914)	0.89444 (0.1793)	0.88333 (0.1575)

( ) Standard errors of observations

§N = 0

TI - Influent

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TABLE 65. MEANS AND STANDARD ERROR FROM TROY, EXPERIMENT #3

Parameter	Station TI	T1	T2	T3	T4
pH	6.5437 (0.0556)	6.5775 (0.0539)	6.5062 (0.0723)	6.5962 (0.0531)	6.4987 (0.1105)
Temp (°C)	19.225 (1.9618)	19.237 (1.9618)	19.237 (1.9618)	19.237 (1.9618)	19.237 (1.9618)
CLF (mg/l)	0.54125 (0.1062)	0.40625 (0.1167)	0.01375 (0.0090)	0.00875 (0.0087)	0.01125 (0.01125)
CLT (mg/l)	0.69250 (0.1123)	0.67250 (0.1103)	0.08000 (0.0188)	0.10375 (0.0170)	0.088750 (0.0209)
Turb (NTU)	0.09333 (0.0021)	0.10667 (0.0168)	0.09500 (0.0056)	0.09167 (0.0079)	0.09333 (0.0080)
DO (mg/l)	7.0714 (0.4648)	7.0571 (0.4571)	6.8857 (0.4677)	6.8714 (0.4799)	6.9571 (0.4339)
LOG[SPC] (CFU/ml)	-0.41892 (0.0606)	-0.26366 (0.1383)	2.6989 (0.3102)	2.1150 (0.3562)	2.6628 (0.5418)
LOG[m-SPC] (CFU/ml)	-2.0808 (0.2632)	-1.1262 (0.2540)	2.3828 (0.3934)	1.6528 (0.5258)	2.4594 (0.4536)
LOG[AF] (CFU/100ml)	-0.61734 (0.2113)	-0.73813 (0.2114)	-0.82542 (0.0902)	-0.58826 (0.1107)	-1.0183 (0.2623)
LOG[TCOLI] (CFU/100ml)	§ -	§ -	§ -	§ -	§ -
Total Endotoxins (µg/l)	0.61167 (0.1624)	0.50920 (0.2282)	0.77217 (0.1839)	0.64080 (0.1799)	0.68100 (0.1537)
Free Endotoxins (µg/l)	0.73100 (0.2316)	0.58083 (0.2313)	0.79914 (0.2029)	0.66060 (0.1840)	0.93229 (0.2923)

(   ) Standard errors of observations
§N = 0
TI - Influent

TABLE 66. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS T2-T3

Variable	Student Mean	Student Sign.	Student N	Pairwise Mean	Pairwise Sign.	Pairwise N
pH	6.6873^{a} 6.8091^{b}	0.2421	11 11	6.6873^{a} 6.8091^{b}	0.3324	11
Temp	3.8400^{a} 3.8400^{b}	1.0000	15 15	3.8400^{a} 3.8400^{b}	-	15
CLF	0.00714^{a} 0.00000^{b}	-	14 14	0.00714^{a} 0.00000^{b}	0.3356	14
CLT	0.11143^{a} 0.07500^{b}	0.1808	14 14	0.11143^{a} 0.07500^{b}	0.0695	14
Turb	0.29154^{a} 0.29000^{b}	0.9789	13 12	0.30500^{a} 0.29000^{b}	0.0786	12
DO	12.662^{a} 12.592^{b}	0.8045	13 13	12.662^{a} 12.592^{b}	0.0323^{*}	13
LOG[SPC]	0.48777^{a} 1.2101^{b}	0.0451^{*}	12 10	0.57854^{a} 1.0230^{b}	0.1004	9
LOG[m-SPC]	2.7011^{a} 3.3903^{b}	0.0047^{*}	8 9	2.7011^{a} 3.3796^{b}	0.0002^{*}	8
LOG[AF]	-0.42883^{a} -0.41813^{b}	0.9527	12 10	-0.42338^{a} -0.41813^{b}	0.9622	10
Total Endotoxins	0.9595^{a} 1.4526^{b}	0.5164	6 5	0.81400^{a} 1.4526^{b}	0.3851	5
Free Endotoxins	1.0123^{a} 1.1126^{b}	0.8478	6 5	0.91880^{a} 1.1126^{b}	0.5095	5

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[a] T2
[b] T3
[*] Significance ≤ 0.05

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TABLE 67. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS T2-T4

Variable	Student Mean	Student Sign.	Student N	Pairwise Mean	Pairwise Sign.	Pairwise N
pH	6.6873^a 6.8864^b	0.2779	11 11	6.6873^a 6.8864^b	0.3471	11
Temp	3.8400^a 3.8400^b	1.0000	15 15	3.8400^a 3.8400^b	-	15
CLF	0.00714^a 0.00000^b	-	14 14	0.00714^a 0.00000^b	0.3356	14
CLT	0.11143^a 0.01429^b	0.0001*	14 14	0.11143^a 0.01429^b	0.0002*	14
Turb	0.29154^a 0.27846^b	0.8220	13 13	0.29154^a 0.27846^b	0.0616	13
DO	12.662^a 12.485^b	0.5357	13 13	12.662^a 12.485^b	0.0039*	
LOG[SPC]	0.48777^a 0.48164^b	0.9823	12 11	0.33739^a 0.46615^b	0.5468	10
LOG[m-SPC]	2.7011^a 3.7430^b	0.0001*	8 8	2.6337^a 3.7217^b	0.0001*	7
LOG[AF]	-0.42883^a -0.39560^b	0.8649	12 10	-0.32665^a -0.39560^b	0.5737	10
Total Endotoxins	0.95950^a 1.8330^b	0.5930	6 5	0.97160^a 1.8330^b	0.3207	5
Free Endotoxins	1.0123^a 1.2482^b	0.3214	6 6	1.0123^a 1.2482^b	0.2771	6

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[a] T2

[b] T4

[*] Significance $\leq$ 0.05

TABLE 68. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #1 COLUMNS T3-T4

	Student			Pairwise		
Variable	Mean	Sign.	N	Mean	Sign.	N
pH	6.8091^a 6.8864^b	0.7001	11 11	6.8091^a 6.8864^b	0.3732	14 14
Temp	3.8400^a 3.8400^b	1.0000	15 15	3.8400^a 3.8400^b	-	15
CLF	0.0000^a 0.0000^b	-	14 14	0.0000^a 0.0000^b	-	14
CLT	0.07500^a 0.01429^b	0.0085*	14 14	0.07500^a 0.01429^b	0.0039*	14
Turb	0.29000^a 0.27846^b	0.8482	12 13	0.29000^a 0.29230^b	0.6872	12
DO	12.592^a 12.485^b	0.7032	13 13	12.592^a 12.485^b	0.0158*	13
LOG[SPC]	1.2101^a 0.48164^b	0.0618	10 11	1.3111^a 0.5406^b	0.0415*	9
LOG[m-SPC]	3.3903^a 3.7430^b	0.1283	9 8	3.3328^a 3.7430^b	0.0007*	8
LOG[AF]	-0.41813^a -0.39560^b	0.8852	10 10	-0.34642^a -0.32406^b	0.6970	8
Total Endotoxins	1.4526^a 1.8330^b	0.7518	5 5	1.6107^a 1.7810^b	0.3649	4
Free Endotoxins	1.1126^a 1.2482^b	0.8276	5 6	1.1126^a 1.1968^b	0.6116	5

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[a] T3
[b] T4
* Significance ≤ 0.05

TABLE 69. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS T2-T3

	Student			Pairwise		
Variable	Mean	Sign.	N	Mean	Sign.	N
pH	6.8550[a] 6.8571[b]	0.9944	14 14	6.8550[a] 6.8571[b]	0.9153	14
Temp	17.200[a] 17.200[b]	1.0000	14 14	17.200[a] 17.200[b]	-	14
CLF	0.0000[a] 0.00786[b]	-	14 14	0.00000[a] 0.00786[b]	0.1667	14
CLT	0.04643[a] 0.06071[b]	0.4552	14 14	0.04643[a] 0.06071[b]	0.2901	14
Turb	0.11385[a] 0.12385[b]	0.5527	13 13	0.11385[a] 0.12385[b]	0.4803	13
DO	7.6917[a] 7.7250[b]	0.9625	12 12	7.6917[a] 7.7250[b]	0.6147	12
LOG[SPC]	-0.07790[a] 0.43316[b]	0.0422*	9 12	-0.07790[a] 0.58365[b]	0.0176*	9
LOG[m-SPC]	-1.0007[a] 0.14606[b]	0.0006*	12 14	-1.0007[a] 0.09959[b]	0.0044*	12
LOG[AF]	-0.27063[a] -0.26277[b]	0.9143	9 8	-0.28247[a] -0.26277[b]	0.7459	8
Total Endotoxins	1.0675[a] 1.1644[b]	0.7345	8 9	1.0675[a] 1.0112[b]	0.6805	8
Free Endotoxins	1.0267[a] 0.8944[b]	0.6210	9 9	1.0267[a] 0.89444[b]	0.4066	9

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[a] T2

[b] T3

* Significance $\leq$ 0.05

TABLE 70. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS T2-T4

Variable	Student Mean	Student Sign.	Student N	Pairwise Mean	Pairwise Sign.	Pairwise N
pH	6.8550[a] 6.8057[b]		14 14	6.8550[a] 6.8057[b]	0.1488	14
Temp	17.200[a] 17.200[b]	1.0000	14 14	17.200[a] 17.200[b]	-	14
CLF	0.0000[a] 0.0150[b]	-	14 14	0.0000[a] 0.01500[b]	0.0431*	14
CLT	0.04643[a] 0.11857[b]	0.0001*	14 14	0.04643[a] 0.11857[b]	0.0000*	14
Turb	0.11385[a] 0.10538[b]	0.3972	13 13	0.11385[a] 0.10538[b]	0.3452	13
DO	7.6917[a] 8.0833[b]	0.5421	12 12	7.6917[a] 8.0833[b]	0.2841	12
LOG[SPC]	-0.07790[a] 0.08001[b]	0.5571	9 11	-0.27455[a] -0.25212[b]	0.4279	8
LOG[m-SPC]	-1.0007[a] -1.4045[b]	0.2481	12 9	-0.86683[a] -1.4927[b]	0.0951	8
LOG[AF]	-0.27063[a] -0.30041[b]	0.8817	9 8	-0.28247[a] -0.30041[b]	0.9156	8
Total Endotoxins	1.0675[a] 1.1167[b]	0.8484	8 9	1.0675[a] 1.0725[b]	0.9709	8
Free Endotoxins	1.0267[a] 0.88333[b]	0.5711	9 9	1.0267[a] 0.88333[b]	0.0352*	9

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[a] T2

[b] T4

* Significance ≤ 0.05

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TABLE 71. STUDENT AND PAIRWISE t-TESTS OF THE GAC PILOT PLANT FROM EXPERIMENT #2 COLUMNS T3-T4

	Student			Pairwise		
Variable	Mean	Sign.	N.	Mean	Sign.	N
pH	6.8571[a] 6.8057[b]	0.8595	14 14	6.8571[a] 6.8057[b]	0.2002	14
Temp	17.200[a] 17.200[b]	1.0000	14 14	17.200[a] 17.200[b]	-	14
CLF	0.00786[a] 0.01500[b]	0.4125	14 14	0.00786[a] 0.01500[b]	0.1827	14
CLT	0.06071[a] 0.11857[b]	0.0037*	14 14	0.06071[a] 0.11857[b]	0.0002*	14
Turb	0.12385[a] 0.10538[b]	0.2350	13 13	0.12385[a] 0.10538[b]	0.1764	13
DO	7.7250[a] 8.0833[b]	0.5555	12 12	7.7250[a] 8.0833[b]	0.2381	12
LOG[SPC]	0.43316[a] 0.08001[b]	0.1640	12 11	0.47714[a] 0.13616[b]	0.1469	10
LOG[m-SPC]	0.14606[a] -1.4045[b]	0.0000*	14 9	0.18168[a] -1.4045[b]	0.0001*	9
LOG[AF]	-0.26277[a] -0.30041[b]	0.8527	8 8	-0.26277[a] -0.30041[b]	0.8542	8
Total Endotoxins	1.1644[a] 1.1167[b]	0.8626	9 9	1.1644[a] 1.1167[b]	0.7469	9
Free Endotoxins	0.89444[a] 0.88333[b]	0.9634	9 9	0.89444[a] 0.88333[b]	0.9345	9

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[a] T3
[b] T4
* Significance ≤ 0.05

TABLE 72. STUDENT AND PAIRWISE t-TESTS COMPARING T2 TO T3 FOR EXPERIMENT #3

	Student			Pairwise		
Variable	Mean	Significance	N	Mean	Significance	N
pH	6.5062^a 6.5962^b	0.3329	8 8	6.5062^a 6.5962^b	0.0903	8
Temp	19.237^a 19.237^b	1.0000	8 8	19.237^a 19.237^b	-	8
CLF	0.01375^a 0.00875^b	0.6972	8 8	0.01375^a 0.00875^b	0.5630	8
CLT	0.08000^a 0.10375^b	0.3647	8 8	0.08000^a 0.10375^b	0.1061	8
Turb	0.09500^a 0.09167^b	0.7387	6 6	0.09500^a 0.09167^b	0.6383	6
DO	6.8857^a 6.8714^b	0.9833	7 7	6.8857^a 6.8714^b	0.7882	7
LOG[SPC]	2.6989^a 2.1150^b	0.2399	7 6	2.8775^a 1.9763^b	0.0821	5
LOG[m-SPC]	2.3828^a 1.6528^b	0.3126	6 3	3.1429^a 1.6528^b	0.0706	3
LOG[acid-fast]	-0.82542^a -0.58826^b	0.1951	3 2	-0.88864^a -0.58826^b	0.0014*	2
Total Endotoxins	0.77217^a 0.64080^b	0.6258	6 5	0.71660^a 0.64080^b	0.1508	5
Free Endotoxins	0.79914^a 0.66060^b	0.6400	7 5	0.61880^a 0.66060^b	0.5037	5

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[a] T2
[b] T3
[*] Significance at 0.05 level

TABLE 73. STUDENT AND PAIRWISE t-TESTS COMPARING T2 TO T4 FOR EXPERIMENT #3

Variable	Student Mean	Student Significance	N	Pairwise Mean	Pairwise Significance	N
pH	6.5062[a] 6.4987[b]	0.9555	8 8	6.5062[a] 6.4987[b]	0.8643	8
Temp	19.237[a] 19.237[b]	1.0000	8 8	19.237[a] 19.237[b]	-	8
CLF	0.01375[a] 0.01125[b]	0.8650	8 8	0.01375[a] 0.01125[b]	0.8795	8
CLT	0.08000[a] 0.08875[b]	0.7603	8 8	0.08000[a] 0.08875[b]	0.6905	8
Turb	0.09500[a] 0.09333[b]	0.8684	6 6	0.09500[a] 0.09333[b]	0.8220	6
DO	6.8857[a] 6.9571[b]	0.9154	7 7	6.8857[a] 6.9571[b]	0.4991	7
LOG[SPC]	2.6989[a] 2.6628[b]	0.9518	7 5	2.8775[a] 2.6628[b]	0.4268	5
LOG[m-SPC]	2.3828[a] 2.4594[b]	0.9008	6 5	2.4346[a] 2.4594[b]	0.7663	5
LOG[acid-fast]	-0.82542[a] -1.0183[b]	0.5250	3 3	-0.82542[a] -1.0183[b]	0.6363	3
Total Endotoxins	0.77217[a] 0.68100[b]	0.7116	6 6	0.77217[a] 0.68100[b]	0.1947	6
Free Endotoxins	0.79914[a] 0.93229[b]	0.7148	7 7	0.79914[a] 0.93229[b]	0.2551	7

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[a] T2
[b] T4

TABLE 74. STUDENT AND PAIRWISE t-TESTS COMPARING T3 TO T4 FOR EXPERIMENT #3

Variable	Student Mean	Student Significance	N	Pairwise Mean	Pairwise Significance	N
pH	6.5962[a] 6.4987[b]	0.4397	8 8	6.5962[a] 6.4987[b]	0.2974	8
Temp	19.237[a] 19.237[b]	1.0000	8 8	19.237[a] 19.237[b]	-	8
CLF	0.00875[a] 0.01125[b]	0.8633	8 8	0.00875[a] 0.01125[b]	0.8741	8
CLT	0.10375[a] 0.08875[b]	0.5866	8 8	0.10375[a] 0.08875[b]	0.2654	8
Turb	0.09167[a] 0.09333[b]	0.8855	6 6	0.09167[a] 0.09333[b]	0.6952	6
DO	6.8714[a] 6.9571[b]	0.8999	7 7	6.8714[a] 6.9571[b]	0.2894	7
LOG[SPC]	2.1150[a] 2.6628[b]	0.4056	6 5	1.9763[a] 2.6628[b]	0.1987	5
LOG[m-SPC]	1.6528[a] 2.4594[b]	0.3032	3 5	1.6528[a] 3.0838[b]	0.0690	3
LOG[AF]	-0.58826[a] -1.0183[b]	0.3051	2 3	-0.58826[a] -0.78674[b]	0.6501	2
Total Endotoxins	0.64080[a] 0.68100[b]	0.8680	5 6	0.64080[a] 0.64220[b]	0.9841	5
Free Endotoxins	0.66060[a] 0.93229[b]	0.4936	5 7	0.66060[a] 0.66020[b]	0.9959	5

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[a] T3
[b] T4

indicate that free chlorine concentrations in the carbon column influents ranging between 0.45 to 1.0 mg/l have no direct influence on effluent microbial water quality parameters. However, during experiment 3, the Troy Water Treatment Plant had to prechlorinate the basins which raised the influent dose of free chlorine into the columns to approximately 1.1 mg/l. The treatments occurred three times and lasted up to seven days (Appendix F).

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APPENDIX A

RAW FIELD DATA

Station C1

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	7.31	12.0	0.00	0.00	1.25	4.96	267.0	---	3.000	---	19.000
15	04/30/80	7.39				1.00	3.68	540.0	278.00			9.000
28	05/13/80	7.90	17.0			0.90	3.44	75.0	---	2.000		4.000
49	06/03/80	7.86	20.5			0.40	5.72	131.0	30.00	3.000		5.000
63	06/17/80	6.94	21.8			0.56	4.20	242.0	---	7.000		4.000
77	07/01/80	7.24	23.0			0.87	5.16	590.0	685.00	1.000		30.000
91	07/15/80	7.20	25.3			0.75	3.20	310.0	---	0.150		0.000
105	07/29/80	6.88	28.0			0.70	3.52	68.0	23.00	0.050		0.670
133	08/26/80	7.06	25.6			0.55	7.32	477.0	---	0.330		8.000
147	09/09/80	7.26	22.0			0.54	5.75	503.0		0.440		0.066
168	09/30/80	7.00	17.0			0.91	3.45	413.0	92.30	0.200	12.00	6.000
182	10/14/80	7.04	12.0			0.71	4.32	300.0	---	0.041	7.63	0.000
196	10/28/80	6.91	9.0			1.25	2.17	780.0		0.670	5.75	3.000
210	11/11/80	7.29	6.0			1.00	5.30	62.0		0.240	7.50	0.330
231	12/02/80	7.06	6.5			1.51	2.90	130.0		0.150	9.40	0.000
287	01/27/81	7.02	3.5			0.50	6.60	13.0		0.074	11.40	0.270
301	02/10/81	6.81	13.0			1.20	4.80	43.0		1.500	5.90	0.000
315	02/24/81	7.25	8.5			1.75	3.10	369.0		0.180	25.80	2.000
329	03/10/81	7.58	6.5			0.90	3.80	60.0		0.870	22.60	0.670
343	03/24/81	7.06	7.0			1.60	3.60	403.0		1.600	16.30	10.000
362	04/13/81	7.20	13.5			1.20	4.30	36.0		0.330	11.20	0.000
375	04/28/81	8.03	15.5			0.50	4.50	176.0		0.090	7.20	
389	05/12/81	7.21	17.0			1.00	4.90	386.0		0.095	9.00	---
403	05/26/81	7.41	22.8			0.60	5.20	433.0		---	9.90	0.000
417	06/09/81	7.32	23.8			0.64	4.00	376.0		0.110	18.10	0.330
431	06/23/81	7.50	24.0			0.63	3.60	1250.0		0.000	10.60	
445	07/06/81	7.60	27.0			0.54	3.90	1336.0	94.00	0.330	14.60	0.000
460	07/21/81	8.40	27.5			0.73	3.30	79.0	---	0.500	23.80	20.000
474	08/04/81	6.70	28.0			0.44	3.50	336.0		0.000	6.20	0.000
496	08/25/81	7.30	24.5			0.49	3.60	1676.0		0.110	14.90	
517	09/15/81	7.71	23.5			0.37	3.50	540.0		0.100	10.90	
531	09/29/81	7.50	16.8			0.45	4.10	756.0		0.000	7.80	

RAW FIELD DATA

Station C2

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	10.23	12.0	0.00	0.00	1.75	6.44	68.0	35.00	---	---	5.000
15	04/30/80	10.10	11.0			0.51	4.69	11.0	158.00	4.000		16.000
28	05/13/80	10.07	16.8			0.45	5.24	40.0	40.00	3.000		0.100
49	06/03/80	9.80	20.5			0.35	3.92	33.0	---			2.000
63	06/17/80	9.69	21.5			1.75	4.36	93.0	115.00	1.000		0.330
77	07/01/80	9.85	23.0			0.56	3.68	126.0	---	3.000		0.000
91	07/15/80	9.79	24.0			0.70	3.44	111.0	111.00	0.900		
105	07/29/80	9.70	27.5			0.50	3.60	116.0	---	0.590		50.000
133	08/26/80	10.20	25.5			0.55	7.27	713.0	233.00	2.000		217.000
147	09/09/80	9.90	22.0			0.42	5.30	566.0	---	0.500		0.000
168	09/30/80	10.50	16.5			0.99	5.66	443.0		0.470	9.00	0.330
182	10/14/80	9.80	12.0			0.61	4.40	176.0		0.130	8.00	7.000
196	10/28/80	10.02	9.0			1.50	3.64	350.0		1.000	5.75	2.000
210	11/11/80	9.90	6.2			1.10	5.22	27.0		0.089	8.00	0.044
231	12/02/80	9.45	6.8			2.00	4.60	110.0		0.740	10.15	0.000
287	01/27/80	10.25	3.5			0.58	7.30	19.0	4.00	0.370	12.00	
301	02/10/81	10.10	6.0			0.80	5.00	113.0	---	0.520	1.90	0.130
315	02/24/81	9.67				1.75	3.50	1273.0		0.130	42.90	3.000
329	03/10/81	10.31	6.8			1.90	4.40	83.0			16.90	0.000
343	03/24/81	10.18	9.0			0.90	3.20	52.0	38.00	0.100	18.40	
362	04/13/81	10.33	13.0			0.86	4.50	65.0	---	0.000	8.90	0.670
375	04/28/81	10.11	14.5			0.75	4.40	64.0		0.270	7.50	0.000
389	05/12/81	9.93	17.0			1.00	5.00	128.0		0.066	11.50	34.000
403	05/26/81	9.83	22.3			0.65		42.0		---	17.30	0.000
417	06/09/81	9.97	22.8			0.75	3.50	128.0		0.780	11.50	
431	06/23/81	10.00	23.0			0.66	3.40	260.0		0.330		
445	07/06/81		26.5			0.54	4.00	138.0		0.080	10.00	
460	07/21/81		25.8			0.45	3.30	403.0			20.20	
474	08/04/81	10.10	27.0			0.42	3.50	120.0		0.000	6.70	
496	08/25/81		23.0			0.40	2.90	523.0		0.250	15.50	
517	09/15/81	10.07	22.5			0.32	3.50	276.0		0.000	5.40	
531	09/29/81	10.10	17.0			0.48	4.00	179.0		0.140	6.60	

RAW FIELD DATA

Station C3

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/81	10.28	11.0	0.00	0.00	1.20	4.60	88.0	---	2.000	---	17.000
15	04/30/80	10.09				0.85	3.44	203.0	158.00	1.000		26.000
28	05/13/80	10.35	16.5			0.60	4.60	228.0	---	3.000		0.200
49	06/03/80	10.10	20.5			0.30	4.68	155.0	101.00	0.660		7.000
63	06/17/80	9.68	22.5			0.41	4.60	160.0	---	2.000		1.000
77	07/01/80	9.97	22.8			0.63	4.80	490.0	320.00	1.000		2.000
91	07/15/80	10.07	24.2			1.20	4.96	116.0	---	2.800		0.330
105	07/29/80	10.24	27.0			0.50	5.84	115.0	119.00	2.300		0.000
133	08/26/80	10.13	24.5			0.75	6.60	227.0	---	0.800		0.330
147	09/09/80	10.05	22.0			0.72	4.67	820.0		0.170		0.066
168	09/30/80	10.28	16.5			0.87	4.42	162.0	140.00	0.140	12.50	2.000
182	10/14/80	9.88	12.0			0.45	4.80	165.0	---	0.130	7.25	0.000
196	10/28/80	9.95	8.5			1.75	4.35	430.0		0.330	8.50	4.000
210	11/11/80	10.43	6.2			1.60	7.50	16.0		0.420	9.70	0.041
231	12/02/80	9.98	5.0			1.25	4.00	157.0		7.000	9.65	0.000
287	01/27/81	9.77	2.0			0.65	8.60	61.0		0.220	6.00	
301	02/10/81	10.20	5.0			0.75	4.90	143.0		0.330	6.25	
315	02/24/81	9.95	6.0			1.43	3.50	803.0		2.200	36.60	4.000
329	03/10/81	10.24	5.5			2.40	4.30	326.0		0.000	16.90	0.000
343	03/24/81	10.18	7.0			4.00	3.70	180.0		3.100	20.80	
362	04/13/81	10.20	12.5			1.00	4.40	189.0	54.00	0.040	13.70	0.330
375	04/28/81	10.14	14.8			0.75	4.50	3000.0	---	0.080	9.20	0.000
389	05/12/81	10.01	18.0			1.15	6.20	403.0		0.000	13.00	0.670
403	05/26/81	10.02	22.0			0.50	5.50	82.0		---	19.30	0.000
417	06/09/81	10.01	22.8			0.73	3.50	199.0		0.150	18.10	
431	06/23/81	10.00	23.8			0.93		880.0		0.470	18.90	0.330
445	07/06/81	10.10	27.0			0.76	3.90	346.0		0.100	14.90	0.000
460	07/21/81	10.00	26.0			0.73	3.70	222.0		0.050	21.90	
474	08/04/81	10.10	28.0			0.76	4.10	---		0.170	6.20	
496	08/25/81		25.0			0.52	4.60	893.0		0.000	16.40	
517	09/15/81	10.08	23.5			0.29	4.00	486.0			0.80	
531	09/29/81	10.10	19.5			0.50	3.80	356.0		---	8.30	

RAW FIELD DATA

Station C4

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	9.80	10.8	0.00	0.00	1.00	6.76	68.0	111.00	---	---	3.000
15	04/30/80	9.69	11.0			0.50	4.52	94.0	---	0.200		8.000
28	05/13/80	9.99	16.5				3.92	50.0	8.00	0.350		0.000
49	06/03/80	10.20	21.0			0.40	4.74	98.0	---	0.300		3.000
63	06/17/80	9.71	21.7			0.30	3.72	57.0	71.00	0.330		1.000
77	07/01/80	10.10	22.8			0.60	3.40	222.0	---	1.000		0.000
91	07/15/80	10.22	24.0			0.50	4.04	79.0	510.00	0.100		
105	07/29/80	9.85	27.0			0.55	8.58	320.0	---	1.400		
133	08/26/80	9.33	24.5			0.75	6.18	335.0		0.700		0.330
147	09/09/80	9.49	22.0			0.64	5.59	490.0	237.00	0.170		0.000
168	09/30/80	10.52	16.0			0.99	4.33	153.0	---	0.180	13.88	5.000
182	10/14/80	9.01	12.0			0.55	4.96	94.0		0.330	9.75	
196	10/28/80	8.06	8.0			1.00	4.56	800.0	106.00		8.50	1.000
210	11/11/80	9.85	6.2			0.80	5.37	21.0	---	0.170	9.90	0.000
231	12/02/80	9.74	4.0			0.75	3.90	133.0		0.044	11.20	
287	01/27/81	9.37	2.0			0.49	6.70	670.0		0.033	11.40	
301	02/10/81	10.20	3.8			0.97	4.90	99.0		0.140	10.80	
315	02/24/81	9.34	5.5			1.70	3.10	286.0		0.130	32.10	6.000
329	03/10/81	10.17	5.0			1.30	3.50	207.0		0.000	21.60	0.000
343	03/24/81	10.31	8.0			1.20	3.60	215.0			14.90	
362	04/13/81	10.19	12.5			0.55	3.80	16.0	35.00	0.170	10.40	0.130
375	04/28/81	10.05	13.5			0.24	3.90	104.0	---	0.040	7.80	0.000
389	05/12/81	10.04	17.8			0.55	4.90	17.0		0.000	16.00	0.130
403	05/26/81	9.94	21.8			0.60	5.00	28.0		---	16.10	0.000
417	06/09/81	10.00	23.5			0.35	3.20	40.0		0.130	9.50	0.670
431	06/23/81	9.90	24.0			0.44	2.90	145.0		0.000	8.40	0.330
445	07/06/81		27.0			0.36	4.50	10.0		0.170	8.50	1.700
460	07/21/81		25.8			0.30	3.10	70.0		0.060	19.40	1.300
474	08/04/81	10.00	27.5			0.25	3.40	---		0.000	---	0.000
496	08/25/81		25.0			0.27	3.20	91.0		0.110	2.10	
517	09/15/81	10.09	23.0			0.22		25.0		0.130	2.40	
531	09/29/81	10.10	19.5			0.26	3.50	39.0		0.000	12.10	

RAW FIELD DATA

Station C5

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	9.80	8.0	0.00	0.18	0.90	4.04	11.0	---	1.000	---	0.000
15	04/30/80	9.68	10.5	0.21	0.33	0.50	3.56	5.0	2.00	0.330		
28	05/13/80	9.91	17.8	0.00	0.18	1.00	3.68	90.0	---	0.100		
49	06/03/80	9.73	17.5	0.24	0.43	0.40	4.36	8.0	13.00	0.300		
63	06/17/80	9.12	21.5	0.21	0.38	0.33	4.32	3.0	---	0.170		
77	07/01/80	9.54	21.0	0.22	0.25	0.46	3.76	5.0	3.00	0.300		
91	07/15/80	9.57	23.8	0.13	0.23	0.60	3.68	3.0	---	0.000		
105	07/29/80	10.05	24.5	0.45	0.45				4.00	0.033		
133	08/26/80	9.91	23.0	0.15	0.35	0.50	6.14	5.0	---	0.038		
147	09/09/80	9.78	22.5	0.20	0.30	0.26	5.36	6.0		0.080		
168	09/30/80	9.94	16.5	0.25	0.35	0.65	4.14			0.100	12.00	
182	10/14/80	9.40	12.0	0.20		0.30	4.40	2.0	2.00	0.160	8.00	
196	10/28/80	9.24	14.5	0.10	0.25	0.90	4.26	9.0	---	0.000	8.40	
210	11/11/80	9.92	7.0	0.30	0.40	1.50	5.94	5.0		0.190	9.00	
231	12/02/80	9.51	9.5	0.20	0.35	0.80	4.80	12.0		0.067	4.00	
287	01/27/81	9.90	4.8		0.30	0.50	6.90	0.0		0.390	10.40	
301	02/10/81	9.50			0.28	0.72	5.60	3.0		0.280	10.80	
315	02/24/81	9.51	4.9	0.30	0.40	0.92	3.10	35.0		0.000	---	
329	03/10/81	9.98	4.5	0.13	0.20	1.00	4.50	16.0			12.70	
343	03/24/81	10.22	5.5	0.20	0.30	2.00	3.70	31.0		0.050	13.90	
362	04/13/81	10.18	9.5	0.10	0.25	0.50	4.50	4.0		0.000	11.00	
375	04/28/81	9.85	9.8	0.15	0.28	0.45	4.30	6.0	2.00	0.100	18.40	
389	05/12/81	9.59	17.2	0.20	0.25	0.95	5.20	3.0	---	0.070	13.00	
403	05/26/81	9.60	16.5	0.15	0.20	0.25	4.50	2.0			11.10	
417	06/09/81	9.66	18.5	0.20	0.28	0.39	3.20	1.0		0.470	12.40	
431	06/23/81	9.70	21.5		0.37	0.45	3.40	3.0		0.040	7.90	
445	07/06/81		22.5		0.20	0.39	4.50	29.0		0.000	10.80	
460	07/21/81			0.23	0.30	0.30	3.30	56.0	5.60	0.100	17.20	
474	08/04/81		22.8	0.25	0.25	0.40	3.90	7.0	---	0.044	---	
496	08/25/81		23.0	0.20	0.15	0.27	3.30	5.3		0.060	4.10	
517	09/15/81	9.75	21.5	0.18	0.25		3.10	2.7		0.055	---	
531	09/29/81	9.80	18.5	0.35	0.48	0.45	3.50	3.3		0.000	6.10	

RAW FIELD DATA

Station C6

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	6.60	9.0	0.00	0.18	1.15	5.04	10.0	4.00	---	---	0.000
15	04/30/80	7.35	10.5	0.20	0.25	0.28	3.16	3.0	---	0.200		0.033
28	05/13/80	7.99	15.8	0.00	0.18	0.35	3.72	2.0	2.00			0.000
49	06/03/80	9.10	17.5		0.19	0.20	4.44	4.0	---	0.030		
63	06/17/80	8.60	18.2	0.05	0.20	0.30	3.60	6.0	10.00	0.470		
77	07/01/80	---	22.0		0.12	0.55	4.40	13.0	---	0.130		
91	07/15/80		19.8	0.00	0.18	0.80	3.24	25.0	27.00	0.200		
105	07/29/80	9.05	24.0	0.40	0.45	0.40	3.84	14.0	---	0.150		
133	08/26/80	8.45		0.18	0.30	0.55	6.33	10.0	11.00	0.100		
147	09/09/80	8.05	22.0	0.13	0.25	0.50	6.88	47.0	---	0.000		
168	09/30/80	8.45	18.0	0.05	0.30	0.64	5.47	19.0		0.190	3.50	
182	10/14/80	8.60	13.0	0.18		0.43	4.36	6.0		0.050	8.75	
196	10/28/80	7.83	15.0	0.10	0.21	0.75	4.55	10.0		0.056	8.90	
210	11/11/80	8.60	13.0	0.05	0.20	1.50	5.32	8.0	5.00	0.067	11.50	
231	12/02/80	8.50	7.0	0.10		1.45	4.40	10.0	---	---	9.50	---
287	01/27/81	7.30	2.5	0.05	0.30	0.48	6.40	2.0		0.051	10.40	0.000
301	02/10/81	6.75	2.8	0.00	0.28	0.85	4.80	3.0		0.000	5.70	
315	02/24/81	---	6.0	0.10	0.30	0.98	2.90	44.0			16.00	
329	03/10/81	9.55	4.8	0.00	0.20	0.81	4.60	21.0			20.70	
343	03/24/81	9.90	3.6	0.05	0.25	1.65	3.90	23.0		0.080	11.80	
362	04/13/81	10.88	9.2	0.00	0.12	0.50		10.0		0.130	10.40	
375	04/28/81	9.15	8.8	0.20	0.25		4.90	30.0	27.00	0.050	8.20	
389	05/12/81	---	12.8	0.15	0.20	1.00	5.20	69.0	---	0.039	13.50	
403	05/26/81	8.70	16.2	0.00	0.18	0.25	6.30	65.0		0.000	13.20	
417	06/09/81	8.78	21.0		0.20	0.55	3.10	22.0		0.110	11.10	0.600
431	06/23/81	8.70	16.3	0.20	0.25	0.75	3.50	356.0		0.000	7.10	0.000
445	07/06/81	9.90	21.5	0.15	0.20	0.48	3.80	242.0		0.110	8.10	
460	07/21/81	8.90	17.8	0.25	0.30	0.46	3.20	94.0	129.00	0.330	12.80	
474	08/04/81	9.00	26.0	0.15	0.20	0.48	3.80	81.0	---	0.000	---	
496	08/25/81	7.10	22.0	0.28	0.30	0.55	3.30	70.0		0.040	4.10	
517	09/15/81	9.25	21.5	0.20	0.25	0.22	3.60	12.0		0.055	0.90	
531	09/29/81	9.15	18.0	0.10	0.30	0.27		11.0		0.000	9.90	

RAW FIELD DATA

Station C7

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	6.80	10.5	0.00	0.10	2.50	3.52	37.0	---	0.000	---	0.000
15	04/30/80	7.40	15.0		0.12	0.65	3.40	29.0	104.00	0.100		
28	05/13/80	8.20	14.8		0.00	0.40	4.52	14.0	---			
49	06/03/80	8.90	19.0		0.15	0.25	4.40	108.0	297.00	0.066		
63	06/17/80	8.98	19.5		0.10	0.30	3.52	231.0	---	0.100		
77	07/01/80	8.35	21.5		0.00	0.48	3.84	221.0	296.00	0.066		
91	07/15/80	---	24.0			1.10	3.80	780.0	---	0.300		
105	07/29/80	9.20	26.0			0.50	6.00	160.0	2800.00	0.080		
133	08/26/80	8.45	24.5			0.45	5.64	337.0	---	0.100		
147	09/09/80	8.35	20.1			0.60	4.92	2943.0		0.033		
168	09/30/80	8.63	23.0		0.10	0.78	3.80	36.0		0.230	13.13	
182	10/14/80	8.40	19.5		0.15	0.52	3.68	50.0	174.00	0.033	9.15	
196	10/28/80	7.45	15.5			0.50	4.75	10.0	---	0.000	7.75	
210	11/11/80	8.50	16.5		0.10	1.00	6.40			0.067	11.50	
231	12/02/80	9.35	15.8			1.25	3.40	45.0		0.033	7.65	
287	01/27/81	7.43	4.5	0.01	0.20	0.60	7.00	0.0		0.000	10.40	
301	02/10/81	8.95	13.0	0.00	0.10	1.20	4.80	11.0			4.80	
315	02/24/81	---	19.0	0.15	0.20	1.50	2.90	20.0			31.20	
329	03/10/81	9.60	12.0	0.00		1.25	3.90	14.0			22.60	
343	03/24/81	9.98	14.2		0.18	1.50	3.20	107.0			11.80	
362	04/13/81	10.88	16.2		0.10	0.55	3.90	21.0		0.070	12.90	
375	04/28/81	8.95	15.2		0.17	0.85	5.40	220.0		0.170	9.70	
389	05/12/81	---	19.0		0.10	0.75	5.70	169.0		0.053	15.00	
403	05/26/81	8.80	22.0			0.60	5.80	163.0		0.190	13.90	
417	06/09/81	8.88	22.2			1.70	3.60	12.0		0.130	18.10	
431	06/23/81	9.05	22.0			0.48	3.20	566.0		0.034	6.00	
445	07/06/81	9.20	25.0	0.10	0.15	0.57	3.50	2290.0		0.220	8.50	
460	07/21/81	9.07		0.00	0.10	0.61	3.40	35.0		0.040	12.10	
474	08/04/81	9.10	28.0		0.15	0.68	3.00	164.0	500.00	0.000	---	
496	08/25/81	---	---	---	---	---	---	---	---	---		---
517	09/15/81	8.90	21.5	0.00	0.11	0.76	4.20	13.0		0.000	3.90	0.000
531	09/29/81	9.35	24.0		0.00	0.62	3.60	35.0			11.70	

RAW FIELD DATA

Station C8

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	6.20	8.0	0.00	0.00	1.15	3.84	21.0	5.00	---	---	0.000
15	04/30/80	6.80	10.0		0.10	0.45	3.36	5.0	---	2.000		
28	05/13/80	7.90	13.8		0.00	0.60	3.40	14.0	17.00	0.000		
49	06/03/80	8.65	19.0			0.40	4.36	6.0	---	0.270		
63	06/17/80	8.30	16.5			0.32	3.92	25.0	57.00	0.230		
77	07/01/80	8.15	19.0		0.01	0.40	3.00	15.0	---	0.200		
91	07/15/80	---	19.8		0.00	0.75	4.32	3593.0	300.00			
105	07/29/80	9.20	23.0			0.40	3.52	168.0	---	0.000		
133	08/26/80	8.25	21.0		0.10	0.50	5.52	497.0		0.100		
147	09/09/80	8.00	22.0		0.00	0.38	4.84	5486.0		0.033		
168	09/30/80	8.35	19.0		0.05	0.65	4.08	65.0		0.120	12.50	
182	10/14/80	7.80	15.0		0.10	0.35	4.40	10.0		0.230	7.25	
196	10/28/80	6.90	14.5		0.13	0.90	4.14	7.0		0.170	10.50	
210	11/11/80	---	---	---	---	---	---	---		---	---	---
231	12/02/80	7.95	6.8	0.00	0.20	1.00	4.00	13.0		0.067	8.65	0.000
287	01/27/81	7.40	3.8		0.10	0.50	6.80	0.7		0.000	6.25	
301	02/10/81	8.40		---	0.28	0.84	4.80	8.0		0.170	27.00	
315	02/24/81	---		0.15	0.25	1.40	4.90	22.0		0.200	18.50	
329	03/10/81	10.00	3.5	0.00	0.15	1.25	3.70	16.0		0.000	22.10	
343	03/24/81	9.90	3.4		0.20	1.00	3.50	31.0		0.100	12.50	
362	04/13/81	---	---	---	---	---	---	---		---	---	---
375	04/28/81		9.2	0.00	0.15	0.85	5.30	7.0		0.150	5.23	0.000
389	05/12/81		12.8		0.07	0.25	5.20	670.0	320.00	0.067	16.50	
403	05/26/81	8.70	15.2		0.10	0.45	6.00	17.0	---	0.300	13.90	
417	06/09/81	8.78	16.2		0.15	0.48	3.30	5.0		0.000	9.70	
431	06/23/81	8.90	18.2		0.07	0.43	4.10	27.0		0.040	6.30	
445	07/06/81	---	---	---	---	---	---	---		---	---	---
460	07/21/81											
474	08/04/81											
496	08/25/81	7.25	22.5	0.00	0.13	0.30	3.10	10.0		0.040	4.60	0.000
517	09/15/81	9.25	21.5		0.10	0.25	3.70	13.0		0.000	4.70	
531	09/29/81	9.35	18.8			0.35	3.90	6.0			7.80	

RAW FIELD DATA

Station M1

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	6.56	9.5	0.00	0.00	1.50	6.96	29.0	---	6.000	---	24.000
15	04/30/80	6.41	11.5			4.20	7.25	25.0		2.000		2.000
28	05/13/80	6.47	14.8			5.70	6.76	40.0		4.000		
49	06/03/80	6.75	20.5			0.40	7.04	66.0	25.00	3.000		4.000
63	06/17/80	6.56				0.54	6.32	340.0	---	5.000		10.000
77	07/01/80	6.52	22.5			0.52	5.00	600.0	850.00	2.000		0.000
91	07/15/80		23.8			0.70	5.40	1063.0	---	0.000		33.000
105	07/29/80	6.53	27.0			0.75		168.0	71.00	0.400		0.000
133	08/26/80		23.3			1.10	6.59	2640.0	---	0.000		
147	09/09/80	6.42	22.5			0.48	8.67	540.0		1.200		
168	09/30/80	6.21	17.0			0.96	5.94	171.0		0.067	4.90	1.000
182	10/14/80	6.26	13.8			0.75	6.16	390.0		0.130	12.60	2.000
196	10/28/80	6.30	9.7			0.55	6.29	190.0		1.600	2.50	10.000
210	11/11/80	6.50	7.0			1.48	8.76	242.0		1.300	11.00	6.000
231	12/02/80	6.82	4.0			0.80	5.30	80.0		1.700	13.25	15.000
287	01/27/81	6.09	3.8			0.53	8.00	5.0	3.00	0.073	5.60	0.000
301	02/10/81	6.26	4.8			4.00	6.70	35.0	---	0.470	3.40	
315	02/24/81	6.09	5.8			0.83	4.00	72.0		0.180	4.10	1.000
329	03/10/81	6.12	5.5			0.65	5.60			0.170	11.10	0.930
343	03/24/81	6.40	3.2			0.95	7.80	69.0		0.130	16.30	1.000
362	04/13/81	6.46	10.2			0.66	5.80	2.0		0.220	8.20	
375	04/28/81	6.26	10.0			0.30	7.60	320.0		0.150	10.30	3.000
389	05/12/81	6.35	15.2	---	---	0.45	6.50	123.0		0.110	8.91	1.300
403	05/26/81	6.43	18.2	0.00	0.00	0.55	6.90	660.0		0.000	13.30	0.000
417	06/09/81	6.38	21.5			0.44	2.90	213.0		1.300	10.90	
431	06/23/81	6.65	24.2			0.25	5.10	903.0		0.056	6.40	
445	07/06/81	6.30	23.5			0.73	5.40	3930.0		0.000	6.10	3.000
460	07/21/81	6.27	24.5	0.05	0.23	0.65	4.60	63.0		0.170	18.70	0.000
474	08/04/81	6.39	25.0	0.00	0.00	0.45	4.90	776.0			---	
496	08/25/81	6.54	23.0			0.73	5.00	1810.0		0.000	4.90	
517	09/15/81	6.57	22.1			0.80	5.60	3500.0		0.170	6.50	
531	09/29/81	6.55	17.0			0.52	5.10	523.0	200.00	0.500	6.10	5.700

RAW FIELD DATA

Station M2

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	5.84	9.0	0.33	0.50	1.35	5.96	9.0	1.00	---	---	0.000
15	04/30/80	5.59	11.0	0.30	0.48	1.55	4.00	5.0	---	2.000		
28	05/13/80	5.79	14.3	0.00	0.20	1.60	5.08	1.0	1.00	4.000		
49	06/03/80	6.15	20.5	0.15		0.45	5.28	3.0	---	1.000		
63	06/17/80	5.80	19.7	0.25	0.35	0.84	4.08	4.0	2.00	0.530		
77	07/01/80	6.52	22.5		0.48	0.44	3.87	19.0	---	0.300		
91	07/15/80	5.99	24.0	0.38	0.45	0.70	4.20	6.0	3.00	0.600		
105	07/29/80	5.56	27.0	0.25	0.30	0.80	4.16	5.0	---	0.100		0.017
133	08/26/80	6.02	23.3	0.80	1.10		5.82	27.0	6.00	0.066		0.000
147	09/09/80	6.01	22.5	0.00	0.25		7.21	3.0	---	0.580		
168	09/30/80	6.25	17.5	0.48	0.62	0.96	5.33	6.0		0.170	0.00	0.110
182	10/14/80	5.80	13.8	0.20	0.30	0.68	5.20	1.0		0.530		0.000
196	10/28/80	5.92	9.8	0.15	0.25	0.92	5.56	3.0		0.250	3.40	
210	11/11/80	6.10	6.8	0.45	0.61	1.15	7.12	2.0		1.300	1.70	
231	12/02/80	5.56	4.8		0.65	1.00	3.90			0.400	2.75	
287	01/27/81	5.79	3.5	0.25	0.50	0.70	7.00	0.3	1.00	0.090	4.25	
301	02/10/81	5.98	4.3	0.00	0.10	0.75	4.40	12.0	---	0.380	0.00	
315	02/24/81	6.11	4.9	0.25	0.38	0.62	3.20	2.0		0.200		
329	03/10/81	5.88	4.5	0.70	0.70	0.86	4.80	14.0		0.033	4.50	
343	03/24/81	6.40	3.2	0.60		0.50	6.50	1.0		1.100	10.30	0.330
362	04/13/81	5.86	9.6	0.15	0.25	0.75	4.10	2.0		0.220	0.00	0.000
375	04/28/81	5.74		0.45	0.50	0.65	5.20	3.0		0.110	3.20	0.110
389	05/12/81	5.94	14.9	---	---	0.95	4.90			0.000	0.00	0.000
403	05/26/81	6.33	18.5	0.15	0.30	0.75	4.40	4.0	3.00		6.50	
417	06/09/81	6.67	21.2	0.00	0.20	0.88	3.60	2.0	---	0.670	12.50	
431	06/23/81	5.98	23.0	0.15	0.25	0.60	3.80	32.0		0.090	4.40	0.110
445	07/06/81	5.92	24.5		0.20	0.84	4.30	156.0		0.000	4.60	0.000
460	07/21/81	5.61	25.3	0.00	0.00	0.53	3.50	217.0		0.330	4.70	
474	08/04/81	5.94	24.8	0.50	0.65	0.75	4.30	---		0.000	---	
496	08/25/81	6.07	23.5	0.45	0.50	0.65	3.80	18.0	20.00		4.60	
517	09/15/81	5.79	21.8	0.38	0.45	0.85	4.00	2.3	---	0.200	0.90	
531	09/29/81		17.0		0.56	0.65	4.40	0.3	0.60	0.170	4.40	

RAW FIELD DATA

Station M3

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	5.96	10.0	0.00	0.10	0.35	4.92	29.0	---	6.000	---	0.000
15	04/30/80	5.48	12.0		0.30	0.42	3.76	1.0	0.00	1.000		
28	05/13/80	6.05	14.3		0.10	0.40	4.24	8.0	---	0.100		
49	06/03/80	6.48	20.5		0.15	0.25	6.40	4.0	1.00			
63	06/17/80	6.05			0.00	0.40	5.64	85.0	---	0.130		
77	07/01/80	5.87	22.5		0.05	0.38	4.16	127.0	10.00	0.200		0.033
91	07/15/80	5.93	24.0		0.00	0.60	3.28	1.0	---	0.050		0.000
105	07/29/80	5.95	27.5	0.20	0.30	0.25	4.56	0.3	0.70	0.067		
133	08/26/80	5.98	23.5	0.00	0.45	0.45	5.05	4.0	---	1.000		
147	09/09/80	6.11	23.0		0.15	0.65	6.67	1.0		0.170		
168	09/30/80	6.04	17.5	0.18	0.35	0.64	5.61	0.0	0.67	0.000	2.75	0.042
182	10/14/80	5.85	14.5	0.00	0.20	0.33	5.72	1.0	0.50	0.044	0.00	0.000
196	10/28/80	6.16	10.3		0.21	0.48	3.93	2.0	0.90	0.000	3.90	
210	11/11/80	6.30	7.6	0.35	0.40	0.55	6.40		0.00	0.073	0.00	
231	12/02/80	5.66	4.0		0.45	0.75	3.70	1.0		0.041	1.90	
287	01/27/81	5.89	4.5	0.05	0.20	0.48	7.10	0.0		0.069	14.25	
301	02/10/81	6.16	5.0	0.10	0.18	0.21	5.00	6.0	4.00	0.041	0.00	
315	02/24/81	6.17	6.1		0.25	0.18	3.00	0.3	0.10	0.000		
329	03/10/81	6.16	5.5	0.90	1.05	0.25	4.70	1.0	0.20		4.20	
343	03/24/81	6.09	3.2	0.35	0.45		6.40	0.0	0.03	0.100	5.10	
362	04/13/81	6.03	10.6	0.00	0.15	0.19	3.90	0.3		0.000	0.00	
375	04/28/81	5.87		0.40	0.50	0.85	4.30		0.00	0.033	2.80	
389	05/12/81	6.12	15.2	---	---	0.25	4.50	0.0	1.00	0.000	1.30	
403	05/26/81	5.80	18.2	0.00	0.20	0.40	4.60	1.0	0.20		6.20	
417	06/09/81	5.76	21.5		0.00	0.44	3.70	15.0	7.00	0.130	7.90	
431	06/23/81	6.01	23.5			0.29	3.30	207.0	77.00	0.110	1.50	
445	07/06/81	5.99	25.0			0.38	4.40	184.0	93.67	0.000	3.90	
460	07/21/81	5.76	24.5			0.24	3.30	250.0	---	0.250	4.70	
474	08/04/81	6.17	25.0	0.25	0.30	0.25	3.50	---	25.00	0.000	---	
496	08/25/81	6.39	24.0	0.15		0.28	4.80	0.3	3.40	0.170	4.60	
517	09/15/81	6.11	21.8	0.08	0.25	0.27	3.40	2.0	0.80	0.000	---	
531	09/29/81	6.20	17.8	0.20	0.32	0.33	4.00	1.3	0.30		4.40	

RAW FIELD DATA

Station M4

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	5.79	9.0	0.00	0.00	0.21	12.12	6.0	7.00	---	---	0.033
15	04/30/80	5.46	11.5			0.22	2.72	1.0	---	0.133		0.100
28	05/13/80	5.82	14.5			0.40	3.36	5.0	7.00	0.200		
49	06/03/80	5.99	20.1			0.35	6.80	12.0	---	0.130		0.000
63	06/17/80	5.85	19.5			0.22	3.68	88.0	11.00			
77	07/01/80	6.02	22.8			0.43	2.96	557.0	---	0.000		
91	07/15/80	6.16	24.0			0.40	4.32	23.0	12.00	0.350		
105	07/29/80	5.90	28.0			0.70	3.40	155.0	---	0.300		
133	08/26/80	5.89	23.5			0.45	4.91	109.0		0.170		
147	09/09/80	5.95	23.0			0.42	4.88	6333.0		0.000		
168	09/30/80	5.80	17.0			0.80	4.22	76.0	78.00	0.033	4.86	
182	10/14/80	5.87	14.0			0.47	4.65	14.0	17.00	0.067	5.75	
196	10/28/80	6.15	10.0			0.65	4.29	38.0	33.00	0.270	0.00	
210	11/11/80	5.50	7.6			0.25	4.86	9.0	0.80	0.000	2.25	
231	12/02/80	6.00	4.0			0.80	3.60	0.3	0.50	0.067	2.75	
287	01/27/81	6.21	3.8			0.32	5.10	3.0	2.00	0.033	0.00	
301	02/10/81	6.40	4.8			0.85	4.70	6.0	6.00	0.260		
315	02/24/81	6.30	5.5			0.47	1.90	0.3	1.00	0.230		
329	03/10/81	6.13	5.0			0.26		14.0	13.00	0.000	4.90	
343	03/24/81	5.93	4.2			0.70	4.60	3.0	0.80	0.170	3.60	
362	04/13/81	5.97	10.0			0.44	2.90	0.7	0.30	0.067	0.00	
375	04/28/81	5.88	10.4			0.55	4.30		0.50	0.000	3.50	
389	05/12/81	5.79	15.4	---	---	0.20	3.40	0.3	3.00		1.90	
403	05/26/81	5.68	17.7	0.00	0.00	0.45	3.60	4.0	0.60	0.033	6.80	
417	06/09/81	5.49	21.8			0.33	2.80	25.0	4.00	0.000	8.90	
431	06/23/81	5.93	23.5			0.43	5.00	179.0	78.00	0.080	1.80	
445	07/06/81	5.90	20.5		0.10	0.47	4.00	126.0	61.30	0.060	6.90	
460	07/21/81	---	25.5		0.00	0.25	2.50	989.0	246.00	0.000	5.10	
474	08/04/81	6.98	25.0			0.28	3.00	63.0	15.00	0.110	---	
496	08/25/81	5.56	23.8			0.25	5.20	123.0	66.00	0.050	5.10	
517	09/15/81	5.90	22.0			0.17	3.10	4.9	22.00	0.000	1.40	
531	09/29/81	5.80	17.5			0.20	3.60	22.0	4.60	0.067	5.30	

RAW FIELD DATA

Station M5

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	6.89	9.8	0.85	1.10	0.43	4.12	2.0	---	0.200	---	0.033
15	04/30/80	7.03	11.5	1.15	1.50	0.64	3.00	1.0	1.00	0.000		0.000
28	05/13/80	7.07	14.0	1.30	1.40	0.25	5.68	2.0	---	0.066		
49	06/03/80	7.65	20.3	0.78	0.85		6.28	5.0	4.00	0.300		0.033
63	06/17/80	7.12	19.5	0.73	0.75	0.06	5.80	1.0	---			0.000
77	07/01/80	6.79	22.5	1.45	1.00	0.34	2.62	3.0	1.00	0.033		
91	07/15/80	7.31	23.8	1.38	1.50	0.30	3.10	1.0	---	0.200		
105	07/29/80	6.71	28.0	1.30	1.30	0.40	3.24	0.0	0.67	0.300		
133	08/26/80	7.09	23.5	1.25	1.55	0.50	5.27	9.0	---	0.430		
147	09/09/80	7.40	22.8	2.10	2.50	0.35	6.67	1.0		0.033		
168	09/30/80	6.87	17.5	1.50	1.75	0.79	3.61	0.3		0.100	6.55	
182	10/14/80	6.83	14.5	0.85	1.10	0.12	3.12	57.0		0.130	0.00	
196	10/28/80	7.53	10.0	0.90	1.15	0.60	3.48	1.0		0.067		
210	11/11/80	7.30	7.5	0.85	1.80	0.25	4.70	2.0		0.130		
231	12/02/80	6.80	3.8	0.88	1.05	1.00	2.80	0.0		0.170	2.80	
287	01/27/81	7.11		0.75	0.95	0.30	5.20	1.0		0.000	0.00	
301	02/10/81	7.46	4.8	0.56	0.65	0.45	4.50		0.03	0.083	2.70	
315	02/24/81	6.95	5.9	0.79	1.40	0.22	2.40	0.3	---	0.067	0.00	
329	03/10/81	7.23	5.3	0.60	0.68	0.20	2.10	2.0		0.022		
343	03/24/81	6.88	3.8	0.65	0.80		4.40	215.0	0.10	---	2.40	
362	04/13/81	7.40	10.6	1.05	1.10	0.33	2.90	1.0	---	0.370	0.00	
375	04/28/81	6.92	10.2	0.75	1.05	0.15	3.00	0.0		0.100	4.90	
389	05/12/81	7.13	15.0	---	---	0.20	2.90	0.3		0.033	3.90	
403	05/26/81	7.24	18.0	0.75	0.95	0.15				0.000	6.80	
417	06/09/81	7.42	22.0	0.60	0.90	0.16	2.60		0.10		13.30	
431	06/23/81	7.95	23.2	0.65	1.35	0.13		1.0	---	0.056	6.70	
445	07/06/81	7.05	24.5	1.20	1.60	0.15	3.30	21.0		0.000	8.10	
460	07/21/81	6.97	25.5	0.80	1.00	0.30	2.30	0.0			3.60	
474	08/04/81	6.99	25.0	0.85	0.96	0.19	3.10			0.040	---	
496	08/25/81	7.38	24.0	1.50	1.70	0.16	3.60			0.000	5.10	
517	09/15/81	7.03	22.0	1.70	1.90		2.90	0.7		0.090	1.80	
531	09/29/81	7.51	17.5	0.80	1.00	0.15	3.60	0.0		0.000	8.70	

RAW FIELD DATA

Station M6

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	5.10	9.9	0.40	0.45	0.60	4.16	1.0	0.03	---	---	0.000
15	04/30/80		11.5	0.48	0.58	1.45	4.32		---	0.033		
28	05/13/80	6.10	13.5	0.43	0.45	0.60	3.40	0.7	0.66	0.200		
49	06/03/80	6.70	18.5	0.51	0.58	0.20	4.60	2.0	---	0.330		0.033
63	06/17/80	7.10	22.1	0.18	0.40	0.24	3.28	23.0	12.00	0.170		0.000
77	07/01/80	6.90	21.5	0.49	0.55	0.45	2.96	1.0	---	0.033		
91	07/15/80	---	22.8	0.68	0.72	0.40	2.12		0.10	0.100		
105	07/29/80	6.30	26.0	0.45	0.70	0.45	3.84		---	0.170		
133	08/26/80	7.15	23.5		0.55		6.00	2.0	0.27	0.100		
147	09/09/80	6.60	24.0	0.58	0.62	0.55	4.59	0.0	---	0.033		
168	09/30/80	6.70	20.0	0.70	0.85	0.60	3.90	2.0			3.40	
182	10/14/80		16.5	0.65	0.80	0.52	3.44			0.130	5.50	
196	10/28/80	6.30	14.5	0.15	0.40	0.38	3.48	1.0		0.170	0.00	
210	11/11/80	---	---	---	---	---	---	---		---	---	---
231	12/02/80	7.20	7.8	0.50	0.73	0.75	3.20	0.0	0.00	0.270	20.00	0.000
287	01/27/81	5.80	5.0	0.35	0.65	0.47	5.10	0.3	---	0.066	0.00	
301	02/10/81	6.65	5.8	0.24	0.45	0.27	4.40	1.0	0.10	0.067		
315	02/24/81	---	8.0	0.30	0.50	0.45	2.30		---	3.400		
329	03/10/81	6.20	6.0	0.35	0.35	0.60	2.10	0.0		0.170	4.90	
343	03/24/81	6.05	5.5	0.25	0.32	0.80	4.70	23.0		0.200	3.50	
362	04/13/81	7.70	9.2	0.30	0.40	0.28	3.10	0.7		0.000	3.60	
375	04/28/81	---	11.0		0.30	0.53	3.50	0.0		0.033	2.80	
389	05/12/81		13.5	---	---	0.60	2.90	0.3		0.067	1.90	
403	05/26/81	6.78	16.0	0.35	0.43	0.20	3.40			0.100	6.50	
417	06/09/81	6.75	20.0	0.70	0.85	0.18	2.70		0.20	0.040	7.10	
431	06/23/81	6.70	22.2	0.25	0.33	0.33	3.20	1.0	---	0.000	6.70	
445	07/06/81	6.90	24.5	0.60	0.75	0.19	3.30	0.0			7.40	
460	07/21/81	7.43	25.5		0.69	0.20	2.50	2.0			12.10	
474	08/04/81	7.20		0.73	0.80	0.35	4.00	0.0			---	
496	08/25/81	6.15	23.8	1.05	1.15	0.23	3.00		1.70	0.110	5.60	
517	09/15/81	7.30	22.5	0.90	1.42		3.60		---	0.000	3.90	
531	09/29/81	7.10	18.8	0.75	0.85	0.17	3.00	0.3			5.30	

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DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)
☆ U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

RAW FIELD DATA

Station M7

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	5.45	11.0	0.33	0.43	0.42	4.04	22.0	---	0.400	---	0.000
15	04/30/80	5.40	11.5	0.35	0.50	0.62	3.64	2.0	0.00	0.066		
28	05/13/80	6.10	13.5	0.33	0.33	0.25	2.80	5.0	---	0.200		
49	06/03/80	6.80	19.0	0.48	0.51	0.10	5.36	12.0	12.00	0.300		
63	06/17/80	6.95	18.2	0.45	0.48	0.12	2.84	1.0	---	0.170		
77	07/01/80	7.00	21.5	0.41	0.45	0.36	2.56	14.0	9.00	0.033		
91	07/15/80	---	23.0	0.58	0.65	0.70	4.40	3.0	---	0.000		
105	07/29/80	6.30	26.0	0.50	0.68	0.20	5.96	2.0	3.00	0.300		
133	08/26/80	7.20	24.0	0.33	0.40	0.50	4.91	4.0	---	0.130		
147	09/09/80	6.55	24.5	0.40	0.45	0.27	4.59	1.0		0.033		
168	09/30/80	6.75	19.5	0.53	0.80	0.53	3.33			0.130	7.00	
182	10/14/80	6.70	16.8	0.75	0.83	0.32	3.28	4.0		0.000	0.00	
196	10/28/80	6.25	13.6	0.25	0.38	0.30	3.23	2.0		0.033	4.25	
210	11/11/80	7.05	11.0	0.53	0.60	0.20	4.32	0.7		0.000	2.25	
231	12/02/80	7.55	7.0	0.40	0.45	0.50	2.90	0.3		0.067	4.90	
287	01/27/81	---	---	---	---	---	---	---		---	---	---
301	02/10/81	6.40	4.2	0.18	0.38	0.38	4.50	1.0		0.000	0.00	0.000
315	02/24/81	---	6.0	0.45	0.45	0.22	2.50	0.3	2.00	0.130		
329	03/10/81	6.30	5.5	0.35	0.48	0.39		1.0	---	0.000	5.90	
343	03/24/81	7.08	5.0	0.25	0.35	0.50	4.60	3.0			7.30	
362	04/13/81	7.60	9.2	0.38	0.48	0.33	3.10	0.0		0.130	4.70	
375	04/28/81	---	10.4	0.30	0.41	0.50	2.70	0.7		0.000	5.10	
389	05/12/81		13.7	---	---	0.30	3.30			0.067	3.90	
403	05/26/81	6.63	16.8	0.00	0.18	0.25	3.40	456.0		0.250	6.20	0.033
417	06/09/81	6.55	19.7	0.25	0.28	0.18	3.00	0.7		0.080	8.80	0.000
431	06/23/81	6.70	22.2	0.12	0.21	0.19	2.90	11.0		0.000	6.90	
445	07/06/81	6.95	25.5	0.40	0.50	0.17	3.90	0.3			7.10	
460	07/21/81	7.10	25.0	0.43	0.55	0.20	2.60	5.0		0.040	7.70	
474	08/04/81	6.95	24.5	0.50	0.60	0.18	2.70	2.6		0.130	---	
496	08/25/81	7.30	23.0	0.70	0.80	0.20		1.3		0.037	4.60	
517	09/15/81	6.50	22.0		0.90	0.27	2.60	1.0	0.70	0.000	0.90	
531	09/29/81	7.10	19.0	0.60	0.70	0.23	3.50	0.3	---		5.30	56.000

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BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
☆ U.S. GOVERNMENT PRINTING OFFICE
TYPING GUIDE SHEET

RAW FIELD DATA

Station M8

Aldate	Date	pH	TEMP	CLF	CLT	TURB	TOC	SPC	m-SPC	AF	ENDOT	TCOLI
0	04/15/80	5.38	8.8	0.28	0.35	1.00	4.32	4.0	0.00	---	---	0.000
15	04/30/80	4.80	11.0	0.15	0.25	0.75	2.92	0.3	---	0.000		0.033
28	05/13/80	5.90	12.5		0.30	0.25	8.80	1.0	0.00	0.100		
49	06/03/80	6.60	17.2	0.20	0.28	0.15	3.90		---	6.000		0.000
63	06/17/80	6.85	17.8	0.18	0.43	0.17	3.08	7.0	0.00	0.100		
77	07/01/80		20.5	0.48	0.55	0.46	2.36	0.0	---			
91	07/15/80	---	21.5	0.45	0.60	0.40	2.32	1.0	0.13	0.050		
105	07/29/80	6.25	24.0	0.43	0.58	0.20		3.0	---	0.067		
133	08/26/80	6.75	23.0	0.00	0.00	0.40	4.51	1.0		0.000		
147	09/09/80	6.20	23.3	0.20	0.28	0.30	6.00	5.0	2.00	0.300		68.000
168	09/30/80	6.40	21.5	0.45	0.65	0.52	3.99	1.0	---	0.033	9.00	0.000
182	10/14/80	6.60	18.0	0.35	0.50	0.40	3.32	0.3		0.050	7.90	0.033
196	10/28/80	6.00	15.8	0.15	0.38	1.25	3.01	6.0		0.067	0.00	0.000
210	11/11/80	6.60	12.8	0.53	0.53	0.15	3.86	3.0		0.000	2.35	
231	12/02/80	6.45	9.8	0.32	0.40	0.60	3.30	0.0	0.20	0.067	3.40	
287	01/27/81	6.05	4.5	0.30	0.38	0.42	5.40		---	0.033	0.00	
301	02/10/81	7.00	4.8	0.20		0.64	5.30	1.0		0.000	5.50	
315	02/24/81	---	6.0			0.65	2.60	0.0	0.33	0.330	49.20	
329	03/10/81	6.35	5.5	0.25	0.37	0.90	2.70	2.0	---	0.033	4.90	
343	03/24/81	6.40	5.2		0.38	0.25	3.90	0.3		0.000	3.90	
362	04/13/81	7.43	9.0	0.38	0.50	0.28	3.70	0.0		0.170	4.30	
375	04/28/81	---	9.6	0.25	0.32	0.20	3.10	0.3		0.000	3.50	
389	05/12/81		12.8	---	---	0.25	3.60	0.7		0.067	3.60	
403	05/26/81	6.65	15.7	0.00	0.15	0.20		0.0		0.000	5.90	
417	06/09/81	6.70	18.2	0.20	0.30	0.18	2.70	0.7		0.230	11.80	
431	06/23/81	6.45	20.7	0.00	0.23	0.20	3.00	5.0		0.040	6.90	
445	07/06/81	6.50	22.5	0.10	0.30	0.30	3.90	1.3		0.000	10.60	
460	07/21/81	6.60	24.0	0.25		0.12	2.50				6.20	
474	08/04/81	6.55	24.5	0.55	0.70	0.25	2.90	3.0			---	
496	08/25/81	6.85	23.0	0.75	0.90	0.21	10.70	0.0			4.10	
517	09/15/81	6.70	22.0	0.41	0.55	0.15	2.70		0.10		---	
531	09/29/81	6.45	19.5	0.40		0.17	3.30	0.3	---	0.037	7.40	